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ABSTRACT

Companies budget and spend a large amount of money each year on maintaining or repairing their buildings. Currently, most companies use historical data to determine an average amount spent and add any known work to forecast their future budgets. This empirical model may have great variance from the actual amount of money spent each year. Budgets are based on the amount of maintenance to be done, so this study examines the prediction of maintenance actions and not the cost of the maintenance. Further studies can link the prediction of maintenance to the cost of that maintenance.

A statistical model (the Weibull Process) has been proven to predict the failures of repairable systems such as electronics and automobiles. It was assumed that buildings could be classified as repairable systems since they are repaired rather than thrown away the first time a component breaks. A linear regression model is also examined as a possible method of predicting maintenance. The Weibull Process and this linear regression model were used to test their applicability to predicting building maintenance.

The tests found that the neither the linear regression or the Weibull Process model could accurately be used to predict the occurrence of maintenance on a set of buildings. The data set used is assumed to be the major reason for these results. Further study of the Weibull Process should be done using variations of the data set.

FORECASTING BUILDING MAINTENANCE USING THE WEIBULL PROCESS

BY

ANN KATHLENE YEOMAN, 1959-

A THESIS

Presented to the Faculty of the Graduate School of the

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MASTER OF SCIENCE IN ENGINEERING MANAGEMENT

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ACKNOWLEDGEMENT

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Finally, I wish to express my sincere thanks to my parents who always believed I could accomplish this and encouraged and supported me through the years.

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I. INTRODUCTION

A. BACKGROUND

A significant part of any company's budget is concerned with maintaining and upgrading their buildings. A company that owns one or more buildings must estimate the amount of maintenance required to keep the building(s) in working order and also estimate the cost of that work. These costs, already high, can have an enormous effect on a company if they are significantly over or under the budgeted amount. Therefore, most companies seek a prediction technique that will help estimate costs to be as close as possible to the amount actually needed.

The most universal method of estimation is by using previous budgets and actual costs and producing a mean value of costs. This figure is used as a starting point to which other known values might be added, values such as planned repairs or preventative maintenance (reroofing or repainting), and increases due to inflation. This provides a deterministic model where budgets are calculated using 'educated guesses' and not by using any statistical model.

A well developed historical deterministic model such as this, with a calculated budget mean, will determine a value at which the company would exceed their budget with a 50 percent probability and have an excess of funds the other 50 percent of the time. The goal for the company manager is to decrease the variance around that mean. For example, a company has 5 years of data on a building with costs for maintenance equal to $8000, $5000, $12000, $12000, and $14000 and an average yearly cost of $10000 (Figure 1). The variance is this case ranges from $5000 under the mean to $3000 exceeding the mean. If the

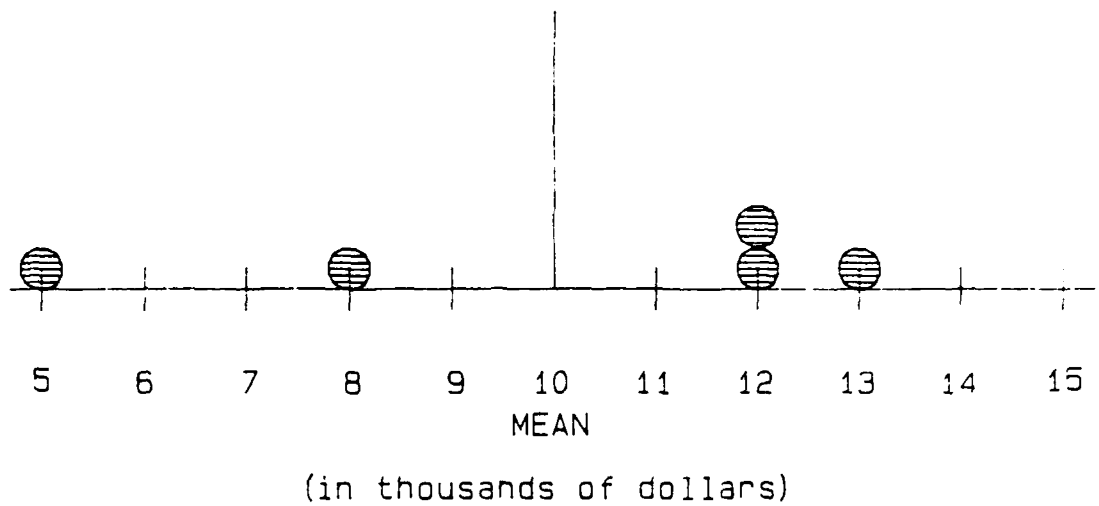

Figure 1. Budget Mean and Variance (wide)

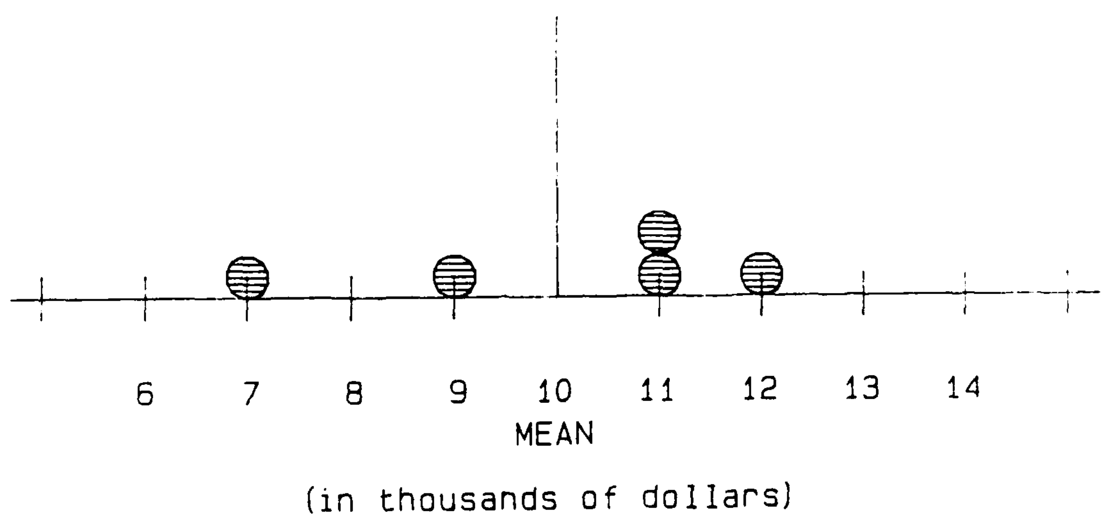

Figure 2. Budget Mean and Variance (narrow)

company budgets for the mean amount each year, then it must be prepared to make funds available in the years that maintenance costs exceeds the mean. The company would either hold separate funds ready for this contingency, or would have to find them from other sources when the need arises. Most react to this problem by overbudgeting their maintenance requirements so that the budget funds will less likely be exceeded. This results in the company earmarking funds for maintenance that have a probability of not being used, and in turn reduces the company's cash flow.

To reduce this effect, the manager needs to reduce the funds being designated for this 'overbudgeting,' or in effect, narrow the variance around the mean. This is also illustrated by example. A company has used a different method to determine its requirements for funds of \$7000, \$9000, \$11000, \$11000, and \$12000 with a mean of \$10000 (Figure 2), and will have a variance range of \$3000 under the mean to \$2000 over the mean. The extra \$1000 difference from the first method which is not being held in contingency could then be committed to other projects, making a significant contribution to that effort. A starting point to accurately predicting budgets can be to more accurately predict the amount of maintenance required. This will be the focus of this study.

A preliminary study [Belcher, 1985] determined that a statistical model, the Weibull Distribution, might be the model for this problem. However, further research into existing literature shows that the Weibull Distribution is primarily concerned with the time until the first failure. A derivation of the Weibull Distribution is a non-homogeneous Poisson Process which focuses on the time between failures of a repairable system. This method is commonly called the

Weibull Process. An assumption is made that a building is a repairable system, and is not replaced after the first failure. Due to this assumption, the Weibull Distribution is not appropriate.

The Weibull Process will be the primary model used in evaluating the applicability to building maintenance. A simple linear regression model will also be checked. Each method will estimate parameter values based on the actual data available, and then evaluate and test the results. A goodness-of-fit test will indicate whether or not these methods are adequate for prediction tools.

If one of the methods is found to accurately predict the occurrences of building maintenance, it could be the starting point to estimating the costs of the maintenance, how many people would be required to maintain the structure, and the time frames of many repairs. Management could use these values to set budgets, adjust manning requirements, and to make better use of time and resources.

B. REVIEW OF LITERATURE

The emphasis in most literature on the Weibull Distribution, the Weibull Process, and system reliability is on the failure of a system. For buildings, this term seems harsh since a building does not fail, a component may simply need repair. Therefore, failure in this study is equated to maintenance or repairs required. It must also be emphasized that preventative maintenance is included in this study even though it is definitely not a 'failure.'

There are many references on reliability available. There is a shortage, however, on reliability of repairable systems. Most reliability theories are based on the time to failure of a nonrepairable

item or the time to first failure of a repairable system. If repair is considered at all, it usually is assumed to renew a system (the Weibull Distribution) to its original condition. "It is empirically obvious that most 'real world' systems are intended to be repaired rather than replaced after failure" [Ascher, Feingold, 1984]. It is important to note that the system is most likely not returned to a good-as-new condition, and that the system is deteriorating over time. Most repair work is concerned with keeping the system in working order. While this study is interested in repairing and not replacing systems, nonrepairable systems are mentioned to show the relationship between the two processes.

For failure rates of nonrepairable systems, extensive research has been conducted which shows that failures can be predicted using the Weibull Distribution model [Mann, Schafer, Singpurwalla, 1974]. The Weibull Distribution gives the probability of failure during a small time increment, provided the system has not failed previously. The failure patterns during three phases of life are similar to Figure 3. During the initial 'breaking-in' period (Figure 3a), some failures occur due to design and manufacturing defects. The number of failures should decline during this time. Figure 3b shows a period of random failures which occur at a steady rate and can be caused by mal-operation [Kelly, Harris, 1979]. The last phase, (Figure 3c), shows an acceleration of the number of failures due to age and wear-out. These three phases of a system life cycle, when combined, produce a 'bathtub curve,' Figure 4. The hazard function of the Weibull Distribution can accurately plot this curve [Hahn, Sharpiro, 1967].

The Weibull Distribution, however, fails to consider repairable

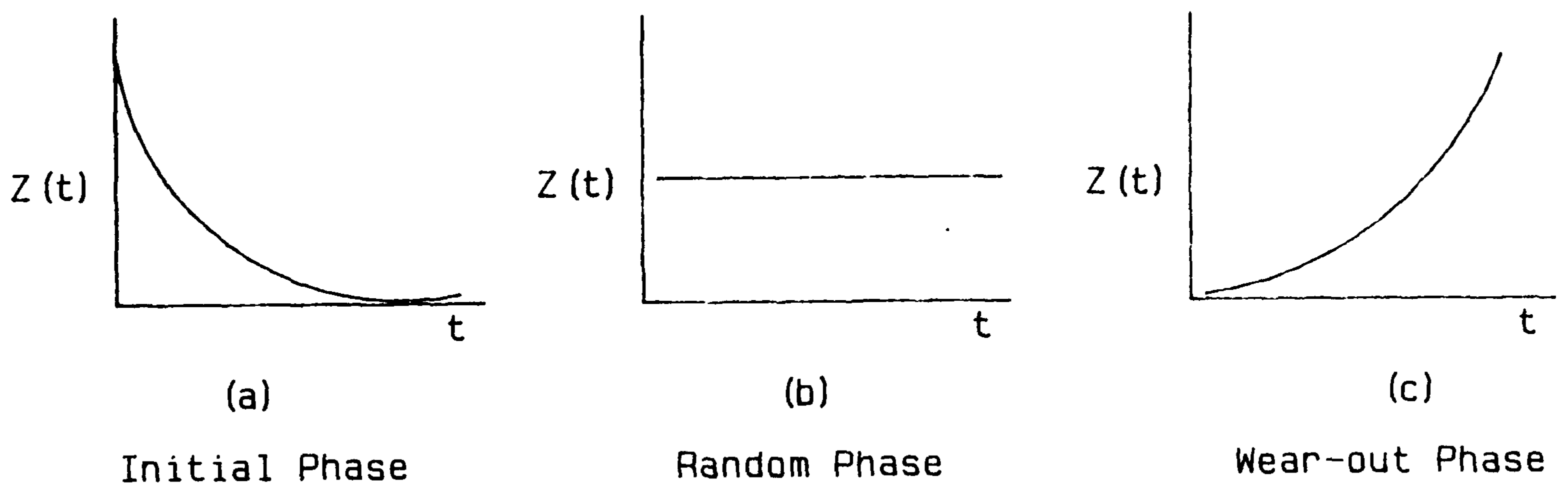

Figure 3. Probability of System Failures Using the Weibull Distribution

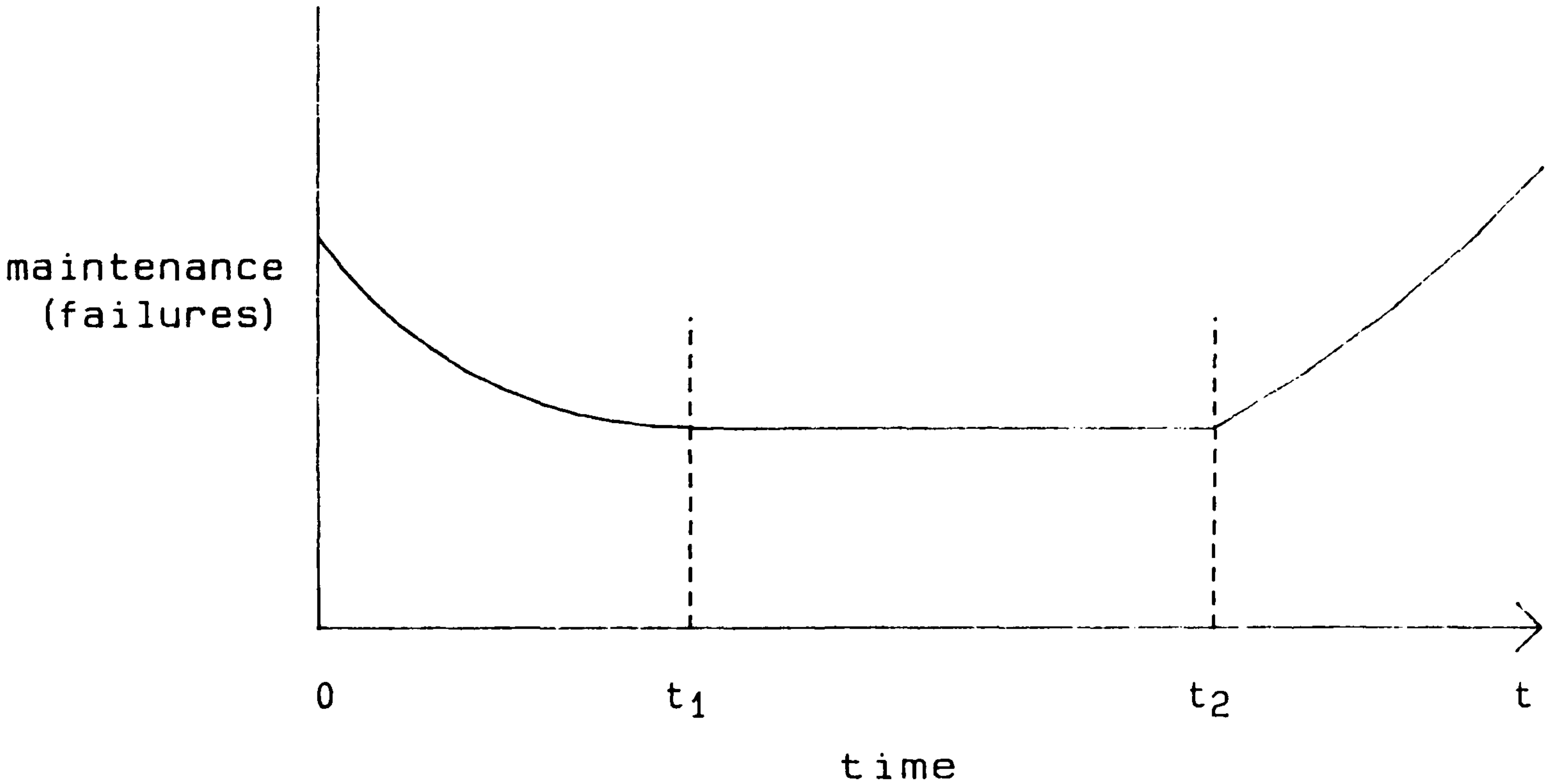

Figure 4. Bathtub Curve

systems. Duane [1964] found that the number of cumulative system failures versus operating time of a repairable system appeared to be concaved downward for a improving system (Figure 5a), and to be concaved upward for an deteriorating system (Figure 5b). In light of this, Crow [1982] proposed a model for which system failure times are predicted to occur following a Weibull Process. The Weibull Process is a stochastic point process, a mathematical model for a physical phenomenon which is described by a counting function, cumulating the number of failures in a time interval of a system and the actual time of failure [Ascher, Feingold, 1984]. The Weibull Process has an intensity function which shows the same pattern of failures as the Weibull Distribution hazard function, the bathtub curve. However, it emphasizes number of repairs and when they occur instead of the failure of the entire system. At the first failure of a repairable system, the intensity function of the Weibull Process equals the hazard rate of the Weibull Distribution.

A time line, with its points of maintenance occurrences, is the input to the Weibull Process model, Figure 6. To accurately test such a model, data representing repair dates with a zero start date would be required, and future values can be found which follow this process.

C. WEIBULL PROCESS

Fig 6 shows a time line and values representing the successive failures of a single system [Ascher, Feingold, 1984]. Two assumptions are that the system is being used whenever possible, and that repair times are negligible. The pattern of failures form on a time line with a starting time 0 and ending time t, (0,t]. The most important consideration of this model is that the failures of a system must occur

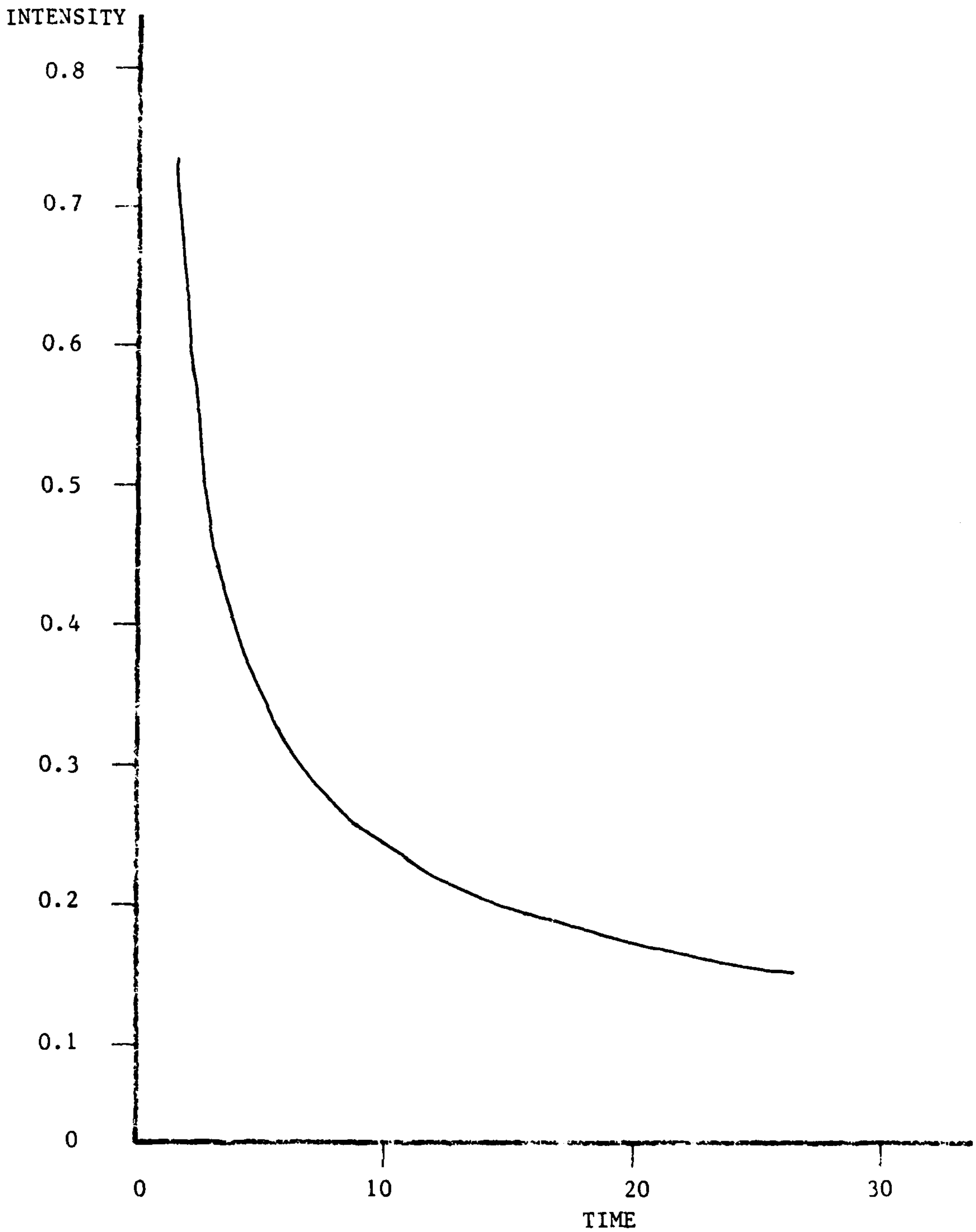

Figure 5. Intensity Function Curves

a. Intensity Function Curve for an Improving System

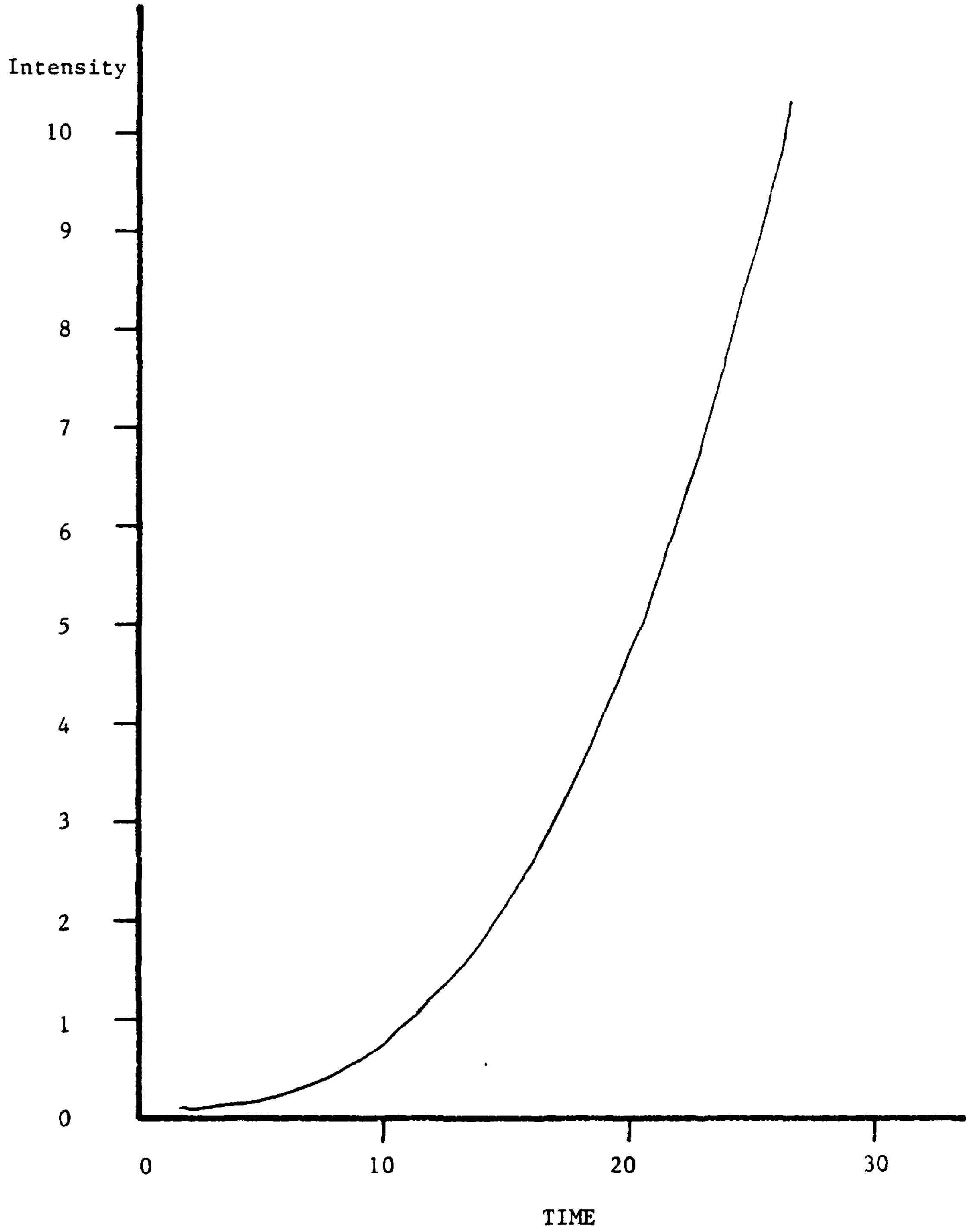

Figure 5 (Con't)

b. Intensity Function Curve for a Deteriorating System

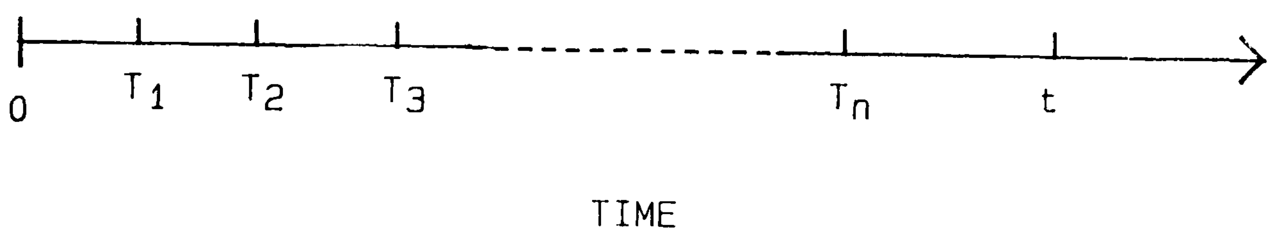

Figure 6. Failure Times of an Interval (0,t]

in a specific sequence.

The Weibull Process is based on a counting function where the number of failures are counted in the time interval (0,t] described above and the time from the beginning (0) and the time of the failure (T) is remembered. The counting function has the following restrictions:

1) $N(0) = 0$;

2) $[N(t), t \geq 0]$ has independent increments; and

3) The number of failures in any interval (t1,t2) has a Poisson distribution with mean

$$\int_{t_1}^{t_2} p(t)dt$$

N(t) is the number of failures which occur in the time interval (0,t], Figure 6. Or more precisely, N(t) is defined as the maximum value of n failures for which $T_n < t$, where t is the length of time the system is being tested, and T_n is the time T of the nth failure. The expected value or mean value is:

$$m(t) = E[N(t)]$$

and for the Weibull process, it is:

$$E[N(t)] = \left(\frac{t}{\theta}\right)^{\beta}$$

The derivative of the mean value gives the intensity function, or the rate of occurrence of failures (ROCOF) of an expected number of failures.

The ROCOF is easily confused with the 'failure rate' which is defined to be equivalent to the hazard rate of the Weibull Distribution (hx(x)). The function h(x)dx is the conditional probability of the first and only failure in the interval (x,x+Δx). The expression v(t)dt is the probability that a failure, not necessarily the first, occurs in the interval (t,t+Δt). With this definition, it is clear that the

Weibull process of a repairable system is equivalent to the Weibull distribution of a nonrepairable system at the first failure time of the system.

In order to estimate or test the hypothesis about the parameters of a Weibull process, this study will use 'time truncation,' in which the process is observed for a fixed time t [Engelhardt, 1986]. The data will have the following form:

1) $N(t) = 0$, or

2) $N(t) = n > 0$ and $0 < T_1 < T_2 < \cdots < T_n < t$.

With t predetermined to be the total time the system is observed, the likelihood function for the failures is

$$f(T_1, T_2, \ldots, T_n, n) = \left(\frac{\beta}{\theta}\right)^n \Pi\left(\frac{T_i}{\theta}\right) \exp\left(-\left(\frac{t}{\theta}\right)\right)$$

and the values $T_1, T_2, \ldots, T_n$ are the individual times to failure. Using this equation to solve for β and θ, the maximum likelihood estimates are:

$$\hat{\beta} = \frac{n}{\Sigma \ln\left(\frac{t}{T_n}\right)}$$

and

$$\hat{\theta} = \frac{t}{n}$$

where n equals the total number of repairs done in time t. A value equal to 1 indicates that the system is constantly being repaired to as-good-as-new and the number of occurrences of failures does not vary over time. A system with this β value is usually considered to be a Poisson process. If the β value is less than one, the system is improving, and the number of failures is decreasing. Conversely, if the β value is greater than 1, the number of failures is increasing and the

system is deteriorating.

To use this model as a forecasting tool, look at the interval $(t, t+\Delta t)$ and use the expected number formula:

$$E[N(t+\Delta t) - N(t)] = \frac{x}{\theta}\Big|_{x=t}^{x=t+\Delta t}$$

The time to repair in this study of the buildings at Fort Leonard Wood will be based on age of the building. For each structure, N(t) will be the number of repairs that occurred while the building was age t.

The linear regression model used is from the Statistical Analysis System (SAS) procedures. Since this is a standard evaluation, no further explanation will be provided. The next step is to test the values estimated for fit with the actual data.

D. GOODNESS-OF-FIT TEST

The most commonly used, and perhaps most versatile procedure for evaluating distribution assumptions is the chi-squared goodness-of-fit test. To use this test, the given data are grouped into frequency cells and compared to the expected number of observations based on the Weibull process. From this comparison, a test statistic is calculated that approximately follows the chi-squared distribution only if the Weibull model is correct. The test statistic will tend to exceed a chi-squared variate if the Weibull model is not correct.

The following procedure is adapted from Hahn and Shapiro [1967] and reflects the process for the Weibull Process instead of a general Chi-squared test. This procedure is used for testing the applicability of the test data.

1) Estimate the unknown parameters (β and θ) of the Weibull

process. This was described in the previous section.

2) Divide the data into cells and determine the probability of a random value from the Weibull model falling within each class. This is described below, following the remaining steps.

3) Multiply the cell probabilities by the total number of repairs, n. This yields the expected number $\underline{E_i}$ of observations for each cell under the Weibull model.

4) Count the numbers of observed values in each cell. Denote this value as $\underline{O_i}$.

5) Compute the test statistic:

$$X^2 = \frac{\Sigma(O_i - E_i)^2}{E_i}$$

6) Compare the computed value X^2 with the tabulated percentiles for a chi-squared variate in a given Chi distribution table, using k-r-1 degrees of freedom, where r is the number of parameters estimated (1 for the Weibull), and k is the number of cells. Values of X^2 that are greater than the degrees of freedom signify that the observed data contradicts the Weibull model.

The cell boundaries are determined by age in years of the building, and each cell is numbered as the age. There will be will be between 42 and 45 cells depending on the year on data being analyzed. Since this method is used, the probability of each cell will be different. Using the cummulative distribution function of the Weibull process, the probabilities are computed. This equation is:

$$Pr(X_k < x) = \left(\frac{x}{t}\right)^{\hat{\beta}} = \frac{k-1}{k}$$

The expected number in each cell is computed by multiplying the probability of each cell with the total number of repairs. For example, if the probability of falling in a certain cell is .25 and there are 100 data points, then multiplying 100 by .25 equals 25, or the number of points that is expected to fall into that cell category. Both the probabilities and the expected number in each cell are cumulative, resulting in the last cell having the entire number of data points. This results in a different plot that has been analyzed before. The resulting graphs show both the expected curve and the actual values overlayed, using the beta value estimated from the actual data. If the graphs are relatively similar and the X^2 values are less than the degrees of freedom as mentioned above, then it can be concluded that the model accurately predicts the data.

II. METHODOLOGY

Detailed and accurate data on building maintenance are required to test the Weibull Process. Information is needed not only on a specific building, but on the major component which was repaired (e.g., plumbing, roof, heating/cooling system, etc.), the extent of the repairs, and the time and money actually spent on the repairs. This requires maintenance data over the entire lifetime of a system from the time the building was built. The data should be highly reliable, and, to use with ease, it should be in an automated form that can be accessed from the University of Missouri-Rolla computer system.

Because of the record keeping procedures currently used by the United States Army on any US Army Installation and their automated Integrated Facilities System (IFS), and because of the nearby location of Fort Leonard Wood, the Department of Engineering and Housing (DEH) at Fort Leonard Wood was contacted regarding the possibility of supplying the appropriate data. The IFS system was designed by the US Army computer system programmers to provide an on-line, responsive tool to aid in maintaining structures on any US Army installations. The relevant data required can be found in the IFS Historical Records (Appendix A). Magnetic tapes containing data from Fiscal Year (FY) 82 to FY 85 (October 1981 to September 1982) were used for testing the model. There are various dates stored in the database for maintenance actions. They include:

1) Date that maintenance was requested (column 102);
2) Date that maintenance was approved (column 108);
3) Date that maintenance was completed (column 162).

Since this study is concerned with the prediction of failures of the system (when maintenance is required), the first date above is used in all calculations.

As of June 1986, Fort Leonard Wood has 2549 buildings that are completed structures and are maintained by the Department of Engineering and Housing. All these buildings were used in this study. Several options were considered on how to analyze these data. The first option was to evaluate all the data on all the buildings as belonging to one system, with the system being 46 years old. The buildings were assumed to be identical and there was no difference in the usage of the building. Maintenance done on a building 5 years old would be counted as maintenance done on the system when it was 5 years old. Since there were 4 years of data available, there is a 4 year shifting window looking at the actual work done on this system. During the life of the system, many subsystems (individual buildings) are added or deleted from the system. No consideration is given to the type of structure, the way it was built, the usage, or whether the Army considers the structure a permanent or temporary building. All these factors could influence the amount of maintenance actually done on a building. This is the option chosen for this study.

Further options for evaluating the data include grouping the buildings into the sections mentioned above, or to look at each building individually. For buildings older than 4 years, there would be an incomplete data set on the entire life of the building. These options should be considered for future study.

A. DATA GATHERING

The DEH at Fort Leonard Wood provided four years of data on 10 magnetic tapes for use in this study. The magnetic tapes had several problems to overcome. First, UMR's IBM 4341 did not recognize the tape labels put on the tapes by Fort Wood's IBM computer. Therefore, each tape label had to be ignored. This was done by including LABEL = 2BLP in the computer software, Appendix C. Duplicates of the tapes were made for storage and later use, and the labels were copied without change. This is to make them compatable to any future tapes received from Fort Leonard Wood.

Second, different years of data had different file layouts and record lengths. This is apparently due to changes in the IFS computer programs. Each tape was 'tape mapped' by the UMR computing services staff to find the block size and record length. These values are listed in Appendix B. Any future data from magnetic tape will also need to be 'mapped.'

Finally, the amount of data gathered from the tapes and used in this study is volumous. Extra space in VS1 was required for reading and storing all the maintenance records for the buildings. Additional space under the Engineering Management account was made available upon request.

Additional data sets were provided by the DEH on the year the buildings were built, the YEAR-BUILT file. Since these values were given in years only, the assumption was made that the buildings were completed in June of each year. This data set was input manually and stored on magnetic tape for future use.

B. DATA ANALYSIS

The first processing of the data occurs when the tapes are first read. There are numerous records stored on tape for files other than the historical file. Only the records that begin with a value of '01' are historical file records. These records are further sifted by checking the year of maintenance. The remaining records are sorted and filed. Appendix C describes the procedure more completely.

The next step is to merge this file of maintenance records with the YEAR-BUILT file (Appendix D). This program removes any records that are not maintenance actions against buildings, such as ground or road work, and only stores valid records. This represents a complete set of data, and no further editting is done. The age of the building is calculated and stored with the maintenance record and is used in plotting time graphs, calculating the number of maintenance occurrences, and used to estimate the Weibull Process parameters.

The third program counts the number of maintenance actions for each building for each year of data and plots it, Appendix E. This cumulative value is used to test for a correlation between age and the number of maintenance actions done on the building for all the buildings at Fort Leonard Wood. Other programs use this value to find a mean, a standard deviation, and the variance of the data for the maintenance done and the age of the building when the work was done.

The next program analyzing the data finds the averages for each year ana plots the values (Appendix F). These averages are useful in finding any outliers or areas that deviate from any expected values.

The remaining programs use the data to estimate the linear regression and the Weibull Process parameters and test them for fit, Appendices G-K. The following sections describe these programs and their theories.

C. TEST MODEL RESULTS

In developing the programs for the Weibull Process parameter estimation, an example of a known Weibull Process was found and the results were duplicated. This example was found in an article by Crow [1982] which gives several ways of estimating the parameters. However, the actual method of parameter estimation also includes equations provided by Engelhardt [1986].

The set of data used was also found in Crow's article. It consisted of 23 sucessive failure times that were generated by a computer simulation of the Weibull Process with the following parameters:

$t = 500 \qquad \beta = .5 \qquad \theta = .945$

The values generated are:

.2	4.2	4.5	5.0	5.4
6.1	7.9	14.8	19.2	48.6
85.8	108.9	127.2	129.8	150.1
159.7	227.4	244.7	262.7	315.3
329.6	404.3	486.2		

Crow's estimated values are:

$\hat{\beta} = .413 \qquad \hat{\theta} = .252 \qquad \text{MTBF} = 52.7$

This first analysis of this test data is a trend graph that plots the cumulative number of failures versus the cummulative operating time using the computed $\hat{\beta}$ value, Figure 7. This figure shows that the system

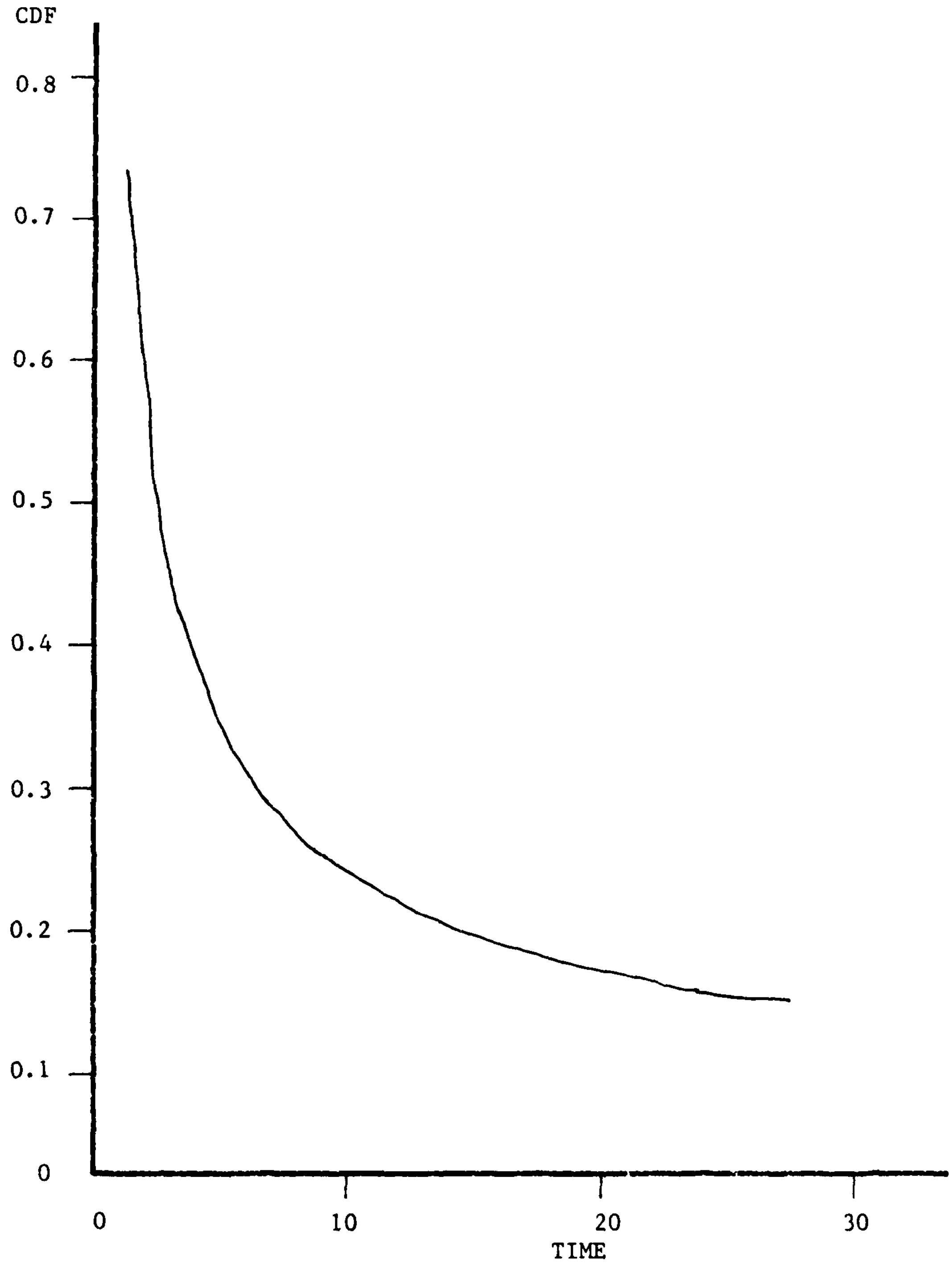

Figure 7. Trend Graph for the Test Data

is improving since the time between failures in increasing and the cummulative distribution function, c.d.f., is decreasing.

This second test of this data is to estimate the $\hat{\beta}$ and $\hat{\theta}$, Figure 8. These $\hat{\beta}$ and $\hat{\theta}$ values are equivalent to Crow's findings. The $\hat{\beta}$ value, which is less than 1, also indicates the system is improving, matching the trend graph.

Finally, a chi-squared goodness of fit test is run to analyze the estimated values, Figure 9. A X^2 value of 2 (Chi) with 3 degrees of freedom (DF) is .425 on the percentiles of the X^2 Distribution [Hahn, Shapiro, 1967], which indicates that the data does not contradict the assumption of being a Weibull Process.

This program, now verified by the test data, is slightly modified to accommodate the bulk of data in the actual test. These modifications include changing the program to run in a batch job environment, and creating separate storage areas for the data (Appendix J). Further, the trends graphs for the data show both the actual values and the values based on the estimated values (Appendix K).

WEIBULL PARAMETERS

OBS	BETAHAT	LAMBDA	THETAHAT	KOUNT	SUMLX
1	0.412738	1.76913	0.251026	23	55.7254

Figure 8. Weibull Process Estimation Values for Test Data

CHI SQUARED GOODNESS OF FIT TEST

TEST MODEL

OBS	T	COUNT	BETAHAT	EXPNUMB	CHI	DF
1	500	23	0.412738	4.6	2	3

Figure 9. Chi Squared Test Results for Test Data

III. RESULTS

A. PRESENTATION OF DATA

1. Mean Analysis: The first analysis done on the data was to count the number of occurrences of repairs for each building, and to plot that value against the age of the structure. The result is Figure 10. This figure shows that between 0 and 30 maintenance actions normally occur on the buildings. However, several areas were unexpected.

One building of age 18 in 1982 (Figure 10a), age 19 in 1983 (Figure 10b), age 20 in 1984 (Figure 10c), and age 21 in 1985 (Figure 10d) shows a significantly higher number than any other building in the entire database. This building was identified as the Post Hospital. It was also unexpected to find a period of years with almost a zero average number of maintenance actions in 1982 data (age 27 through 37, Figure 10a), and that value moves by one age group for each year of data signifying that the same buildings are not being maintained. These buildings were built between 1945 and 1955. This area is further examined in the next section.

The next procedure runs a simple mean software package which provides the values shown in Figure 11. For each year of data, and for a combined data set, the mean value, standard deviation, variance, and other values are computed on the number of maintenance actions on one building. Figure 11e describes the entire database as having 2 maintenance actions per building average, a minimum value of 0, maximum of 220, with a standard deviation of 7.078 and variance of 50.1. These values could be abnormal due to the influence of outliers. To help

PLOT OF MAINTENANCE VS AGE FOR 1982 DATA

PLOT OF COUNT*AGE   SYMBOL USED IS *

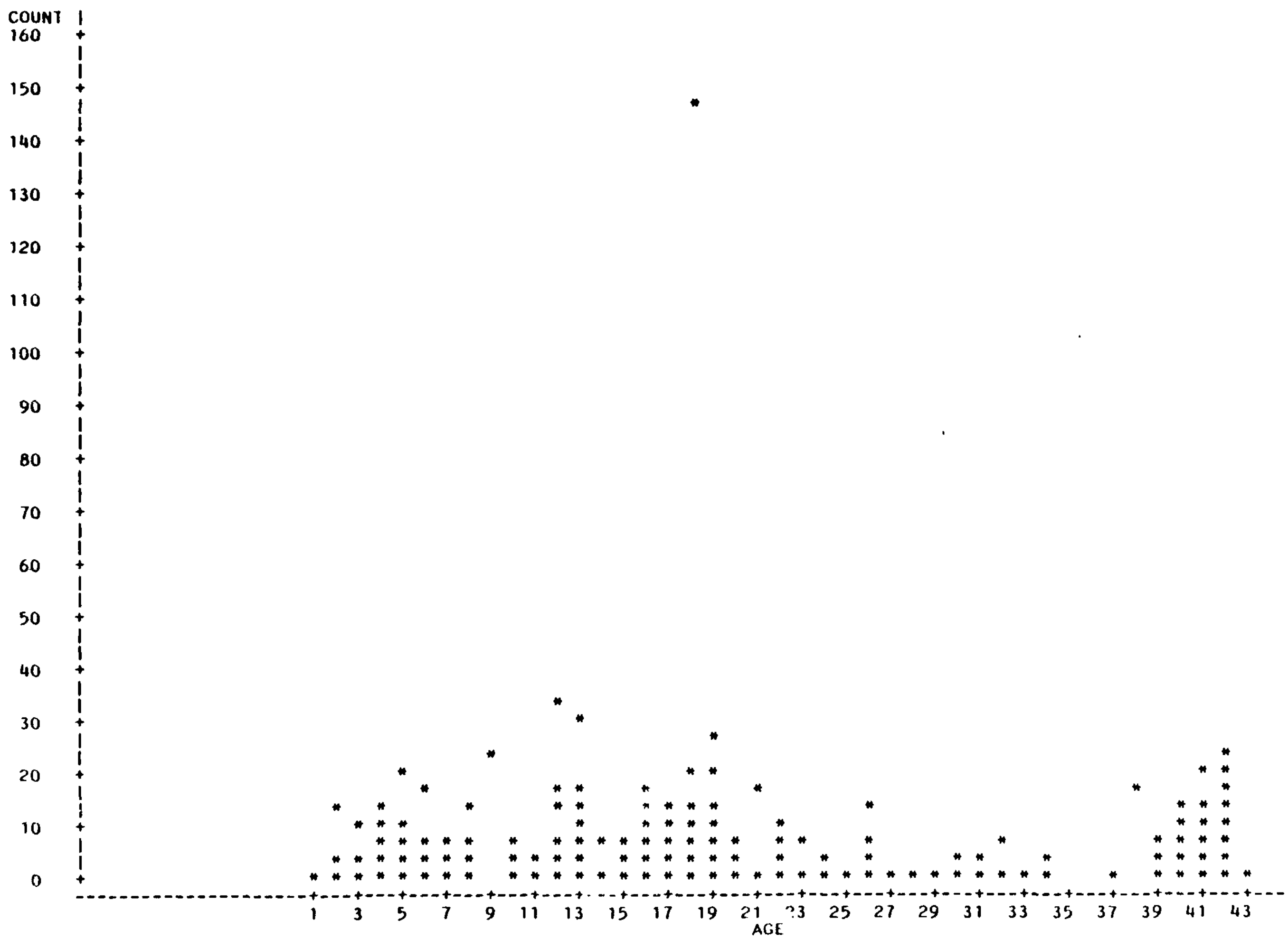

Figure 10. Plot of Maintenance vs Age a. 1982 Data

PLOT OF MAINTENANCE VS AGE FOR 1983 DATA

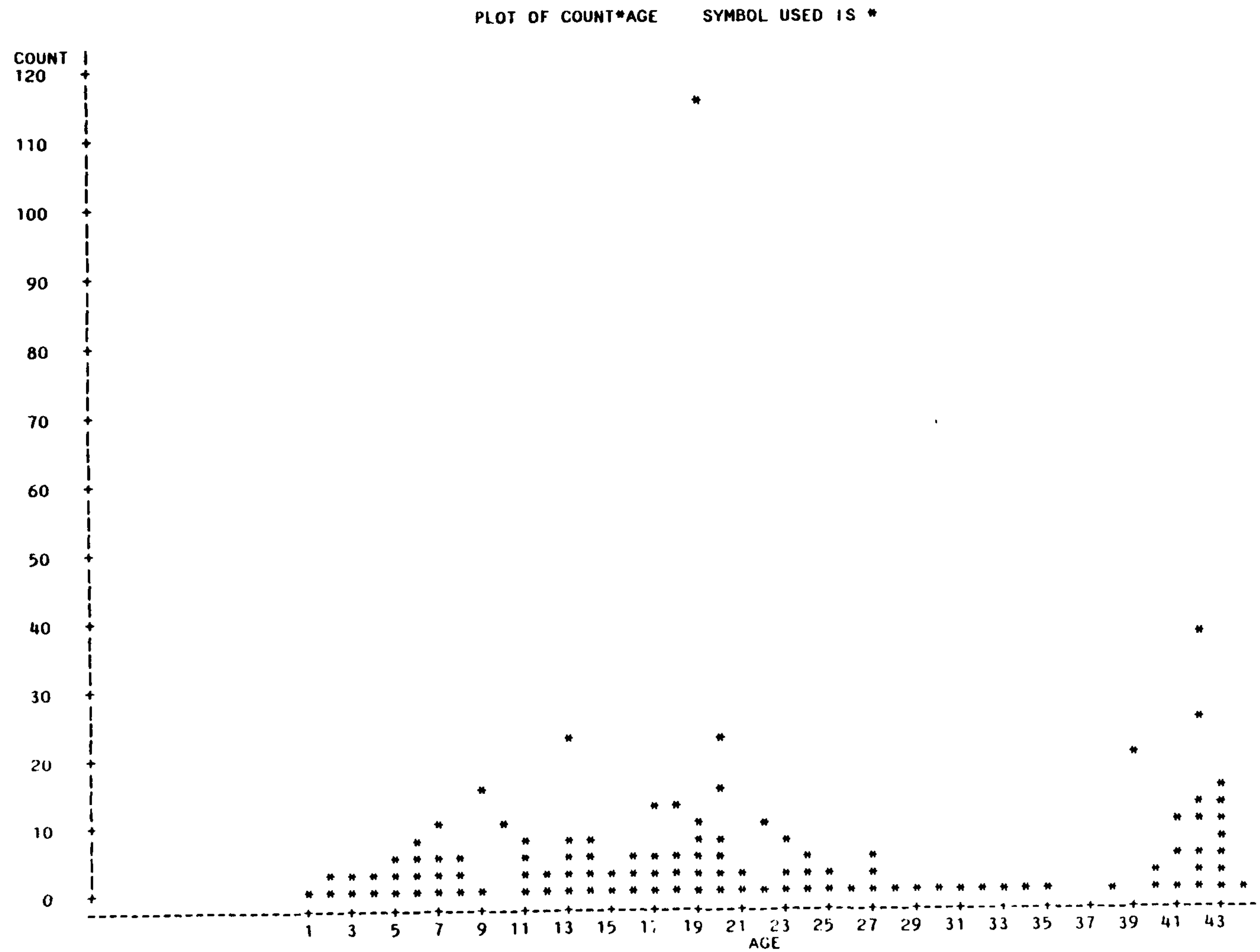

Figure 10 (Con't)   b. 1983 Data

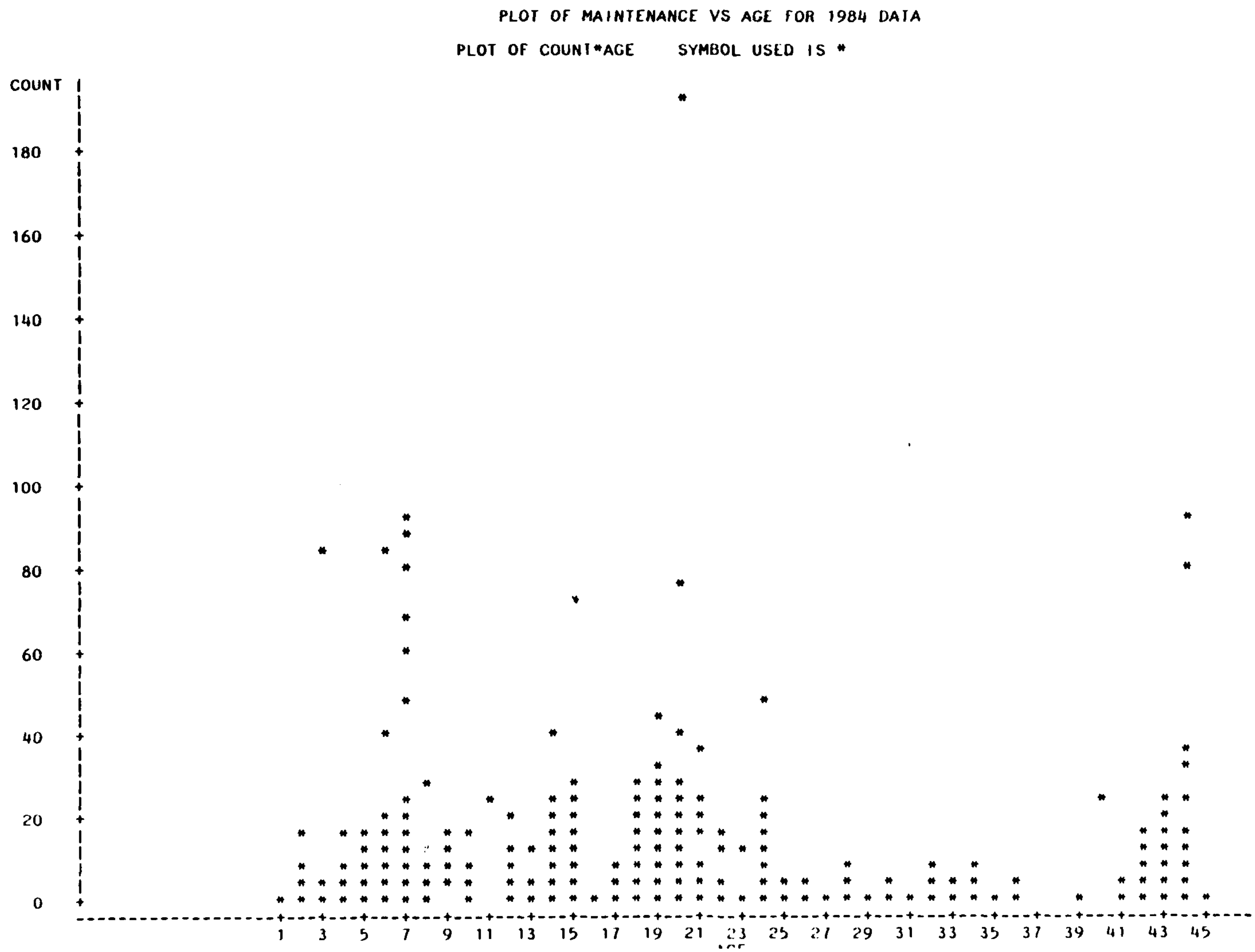

Figure 10 (Con't) c. 1984 Data

PLOT OF MAINTENANCE VS AGE FOR 1985 DATA

PLOT OF COUNT*AGE   SYMBOL USED IS *

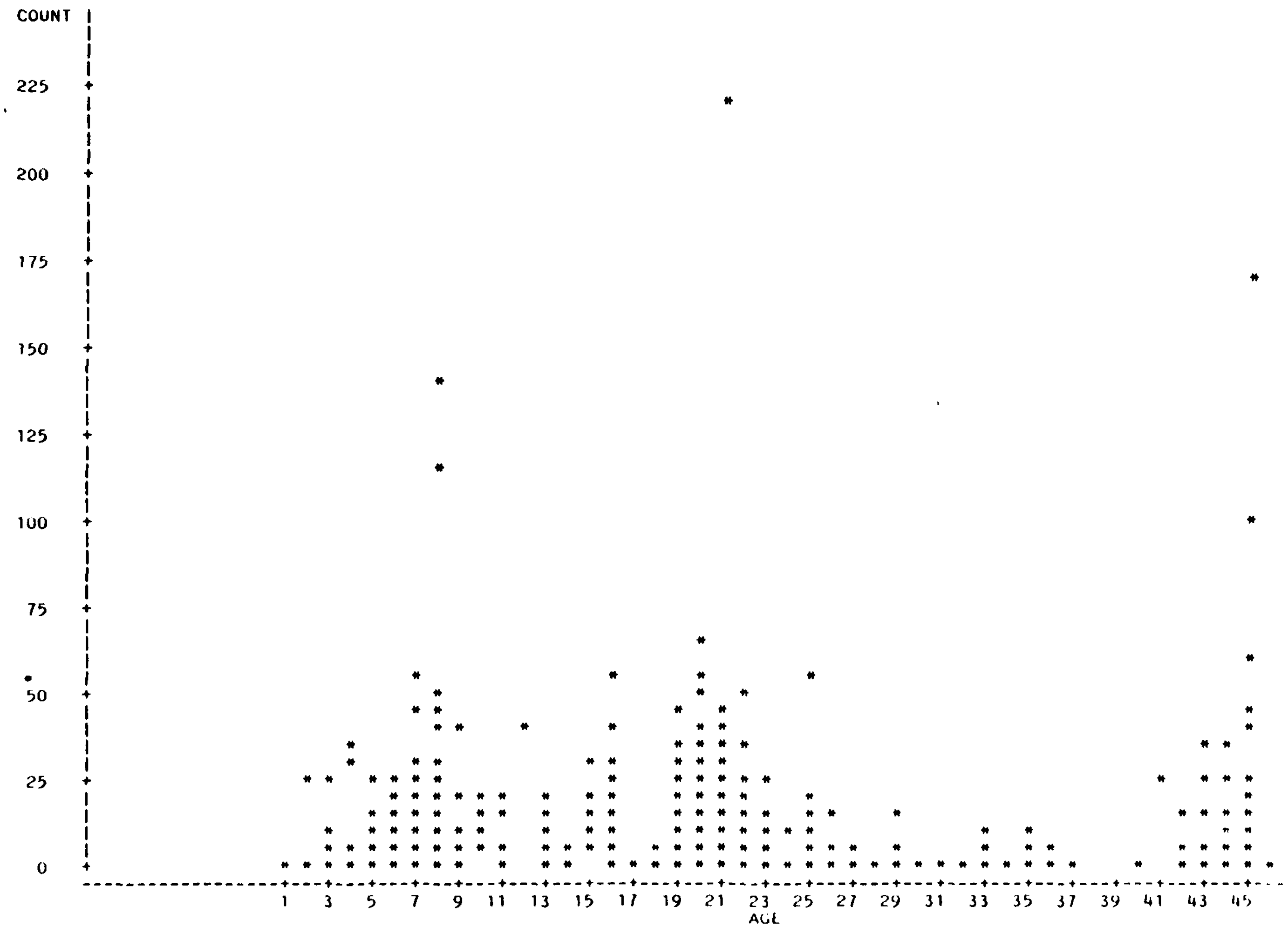

Figure 10 (Con't)   d. 1985 Data

PLOT OF MAINTENANCE VS AGE FOR ALL DATA

PLOT OF COUNT*AGE   SYMBOL USED IS *

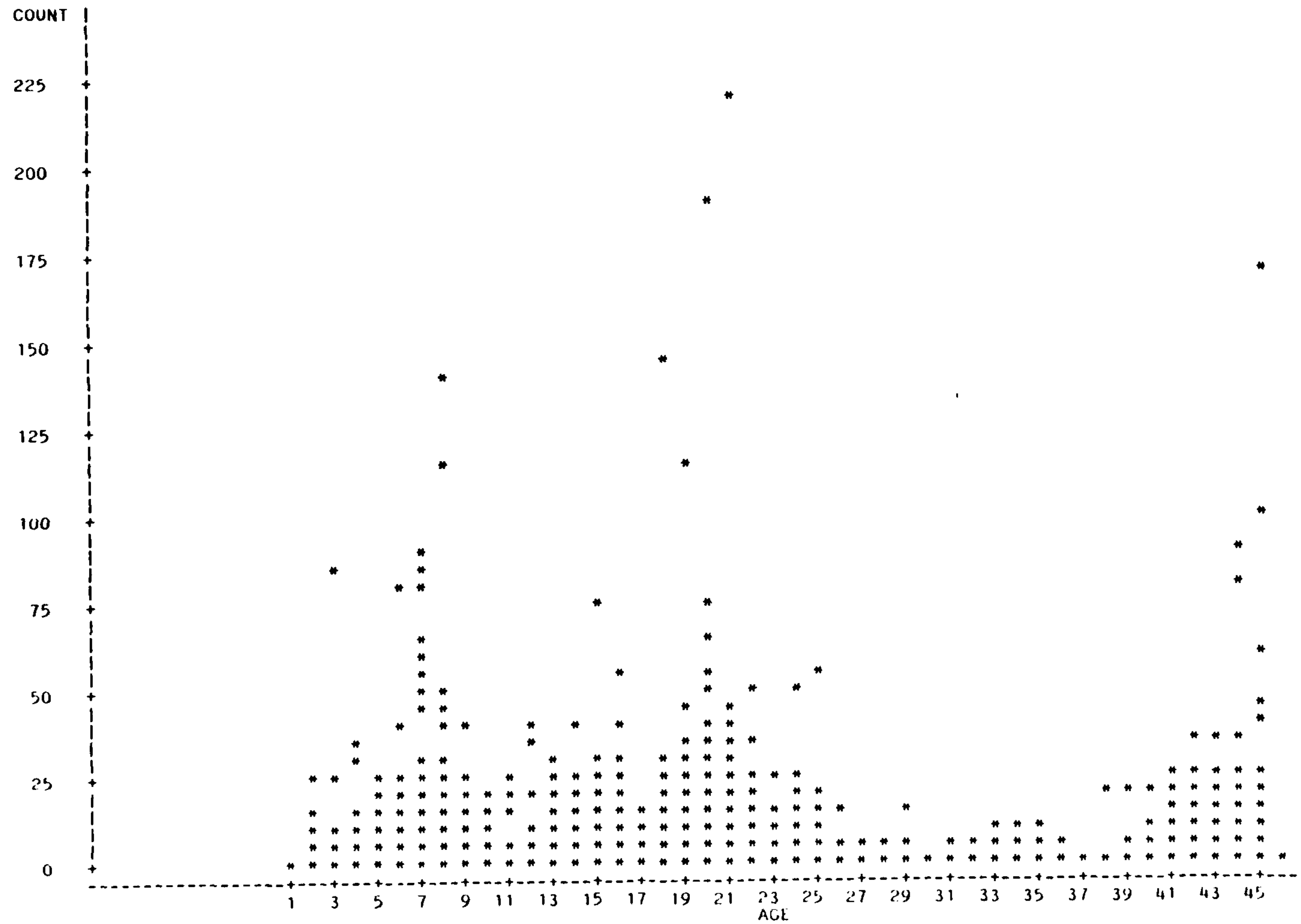

Figure 10 (Con't)   e. All Data Combined

FT LEONARD WOOD BUILDING 1982 DATA

SIMPLE MEAN OF DATA

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE
COUNT	2520	1.13015873	4.01739508	0	145.00000000	0.08002843	2848.0000000	16.13946325

FT LEONARD WOOD BUILDING 1982 DATA

REQUESTED STATISTICS

VARIABLE	N MISSING	RANGE	UNCORRECTED SS	CORRECTED SS	SKEWNESS	KURTOSIS	T	PR>|T|
COUNT	0	145.000000000	43874.0000000	40655.3079365	19.7326043233	658.367471071	14.12	0.0001

Figure 11. Simple Mean and Statistics

a. 1982 Data

FT LEONARD WOOD BUILDING 1983 DATA

SIMPLE MEAN OF DATA

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE
COUNT	2534	0.57774270	2.96686429	0	114.00000000	0.05893786	1464.0000000	8.80228373

FT LEONARD WOOD BUILDING 1983 DATA

REQUESTED STATISTICS

VARIABLE	N MISSING	RANGE	UNCORRECTED SS	CORRECTED SS	SKEWNESS	KURTOSIS	T	PR>|T|
COUNT	0	114.000000000	23142.0000000	22296.1846882	24.1738929285	858.789571373	9.80	0.0001

Figure 11 (Con't)

b. 1983 Data

FT LEONARD WOOD BUILDING 1984 DATA

SIMPLE MEAN OF DATA

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE
COUNT	2541	2.59386068	8.31635482	0	192.00000000	0.16497976	6591.0000000	69.16175757

FT LEONARD WOOD BUILDING 1984 DATA

REQUESTED STATISTICS

VARIABLE	N MISSING	RANGE	UNCORRECTED SS	CORRECTED SS	SKEWNESS	KURTOSIS	T	PR>|T|
COUNT	0	192.000000000	192767.000000	175670.864227	9.60982596139	146.121404595	15.72	0.0001

Figure 11 (Con't)

c. 1984 Data

FT LEONARD WOOD BUILDING 1985 DATA

SIMPLE MEAN OF DATA

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE
COUNT	2544	3.71933962	9.98948737	0	220.00000000	0.19805447	9462.0000000	99.78985784

FT LEONARD WOOD BUILDING 1985 DATA

REQUESTED STATISTICS

VARIABLE	N MISSING	RANGE	UNCORRECTED SS	CORRECTED SS	SKEWNESS	KURTOSIS	T	PR>|T|
COUNT	0	220.000000000	288958.000000	253765.608491	9.12768253398	141.802072659	18.78	0.0001

Figure 11 (Con't)

d. 1985 Data

FT LEONARD WOOD BUILDING ALL DATA

SIMPLE MEAN OF DATA

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE
COUNT	10139	2.00858073	7.07759499	0	220.00000000	0.07028913	20365.000000	50.09235091

FT LEONARD WOOD BUILDING ALL DATA

REQUESTED STATISTICS

VARIABLE	N MISSING	RANGE	UNCORRECTED SS	CORRECTED SS	SKEWNESS	KURTOSIS	T	PR>|T|
COUNT	0	220.000000000	548741.000000	507836.253477	12.0713512294	242.574509663	28.58	0.0001

Figure 11 (Con't)

e. All Data Combined

identify these outliers, the average number of maintenance actions on the buildings of each age group are computed.

2. Averages: The data for each year is averaged resulting in Tables 1 and 2, and Figure 12. These values can be used in predicting the amount of maintenance for a building of a certain age, similar to the budget predictions by using past budget amounts. However, it is easily seen that the values can change dramatically between years.

The table also emphasizes the zero or near zero averages of all the years of data over a period of years, ages 22 through 36. Looking at Table 2, the total number of buildings in this time frame is, at first, very high and then drops to a very low number. The DEH personnel explained both areas. Following World War II until the start of the Korean Conflict, and after the Korean Conflict until 1957, Fort Leonard Wood was not an active Army Installation and very little construction occurred. When the Post was reopened as a permanent installation in 1958, a flurry of construction began, and these new buildings were considered permanent structures, usually constructed from brick or concrete as opposed to the older wooden buildings.

3. Outliers: Table 1 points out several more age groups where the average number of maintenance actions is higher than any other. These are also due to high maintenance to a particular building, the Headquarters building and the hospital annex, along with the main hospital.

The Installation also increased their construction of family housing units. These buildings are the majority of the total number of

Table I

Buildings and Maintenance for all Data

OBS	AGE	BLDG82	MAINT82	AVE82	BLDG83	MAINT83	AVE83	BLDG84	MAINT84	AVE84	BLDG85	MAINT85	AVE85
1	1	23	23	1.0000	20	2	0.1000	14	55	3.9286	7	31	4.4286
2	2	42	31	0.7381	23	6	0.2609	20	92	4.6000	14	89	6.3571
3	3	28	67	2.3929	42	9	0.2143	23	70	3.0435	20	77	3.8500
4	4	72	146	2.0278	28	24	0.8571	42	151	3.5952	23	85	3.6957
5	5	35	45	1.2857	72	70	0.9722	28	266	9.5000	42	230	5.4762
6	6	13	24	1.8462	35	21	0.6000	72	816	11.3333	28	318	11.3571
7	7	6	22	3.6667	13	8	0.6154	35	114	3.2571	72	956	13.2778
8	8	1	23	23.0000	6	18	3.0000	13	105	8.0769	35	177	5.0571
9	9	12	24	2.0000	1	10	10.0000	6	28	4.6667	13	122	9.3846
10	10	3	5	1.6667	12	22	1.8333	1	24	24.0000	6	41	6.8333
11	11	15	103	6.8667	3	3	1.0000	12	83	6.9167	1	40	40.0000
12	12	27	123	4.5556	15	49	3.2667	3	14	4.6667	12	111	9.2500
13	13	3	7	2.3333	27	25	0.9259	15	191	12.7333	3	11	3.6667
14	14	23	27	1.1739	3	2	0.6667	27	297	11.0000	15	254	16.9333
15	15	42	120	2.8571	23	13	0.5652	3	1	0.3333	27	375	13.8889
16	16	159	268	1.6855	42	30	0.7143	23	60	2.6087	3	2	0.6667
17	17	31	327	10.5484	159	74	0.4654	42	321	7.6429	23	47	2.0435
18	18	25	123	4.9200	31	175	5.6452	159	668	4.2013	42	487	11.5952
19	19	108	26	0.2407	25	73	2.9200	31	699	22.5484	159	1259	7.9182
20	20	328	16	0.0488	108	4	0.0370	25	202	8.0800	31	830	26.7742
21	21	149	66	0.4430	328	9	0.0274	108	47	0.4352	25	269	10.7600
22	22	429	11	0.0256	149	23	0.1544	328	12	0.0366	108	118	1.0926
23	23	154	8	0.0519	429	9	0.0210	149	211	1.4161	328	10	0.0305
24	24	2	0	0.0000	154	6	0.0390	429	8	0.0186	149	239	1.6040
25	25	33	24	0.7273	2	0	0.0000	154	10	0.0649	429	33	0.0769
26	26	1	0	0.0000	33	10	0.3030	2	0	0.0000	154	83	0.5390
27	27	2	0	0.0000	1	0	0.0000	33	16	0.4848	2	2	1.0000
28	28	3	0	0.0000	2	0	0.0000	1	0	0.0000	33	64	1.9394
29	29	19	8	0.4211	3	0	0.0000	2	2	1.0000	1	0	0.0000
30	30	19	11	0.5789	19	2	0.1053	3	1	0.3333	2	0	0.0000
31	31	9	8	0.8889	19	0	0.0000	19	30	1.5789	3	2	0.6667
32	32	2	0	0.0000	9	1	0.1111	19	5	0.2632	19	37	1.9474
33	33	11	2	0.1818	2	0	0.0000	9	14	1.5556	19	6	0.3158
34	34	0	0	0.0000	11	0	0.0000	2	0	0.0000	9	15	1.6667
35	35	0	0	0.0000	0	0	0.0000	11	3	0.2727	2	5	2.5000
36	36	1	1	1.0000	0	0	0.0000	0	0	0.0000	11	4	0.3636
37	37	1	18	18.0000	1	1	1.0000	0	0	0.0000	0	0	0.0000
38	38	5	13	2.6000	1	21	21.0000	1	1	1.0000	0	0	0.0000
39	39	12	45	3.7500	5	4	0.8000	1	22	22.0000	1	1	1.0000
40	40	80	202	2.5250	12	30	2.5000	5	6	1.2000	1	27	27.0000
41	41	571	881	1.5429	80	151	1.8875	12	44	3.6667	5	27	5.4000
42	42	1	0	0.0000	571	566	0.9912	80	274	3.4250	12	88	7.3333
43	43	0	0	0.0000	1	0	0.0000	571	1688	2.9562	80	406	5.0750
44	44	0	0	0.0000	0	0	0.0000	1	0	0.0000	571	2485	4.3520
45	45	0	0	0.0000	0	0	0.0000	0	0	0.0000	1	0	0.0000
46	46	0	0	0.0000	0	0	0.0000	0	0	0.0000	0	0	0.0000

Table II

Buildings and Maintenance for all Data, Totals

OBS	TOTBLDG	TOTMAINT	AAVER
1	64	111	1.73438
2	99	218	2.20202
3	113	223	1.97345
4	165	406	2.46061
5	177	611	3.45198
6	148	1179	7.96622
7	126	1100	8.73016
8	55	323	5.87273
9	32	184	5.75000
10	22	92	4.18182
11	31	229	7.38710
12	57	297	5.21053
13	48	234	4.87500
14	68	580	8.52941
15	95	509	5.35789
16	227	360	1.58590
17	255	769	3.01569
18	257	1453	5.65370
19	323	2057	6.36842
20	492	1052	2.13821
21	610	391	0.64098
22	1014	164	0.16174
23	1060	238	0.22453
24	734	253	0.34469
25	618	67	0.10841
26	190	93	0.48947
27	38	18	0.47368
28	39	64	1.64103
29	25	10	0.40000
30	43	14	0.32558
31	50	40	0.80000
32	49	43	0.87755
33	41	22	0.53659
34	22	15	0.68182
35	13	8	0.61538
36	12	5	0.41667
37	2	19	9.50000
38	7	35	5.00000
39	19	72	3.78947
40	98	265	2.70408
41	668	1103	1.65120
42	664	928	1.39759
43	652	2094	3.21166
44	572	2485	4.34441
45	1	0	0.00000
46	0	0	.

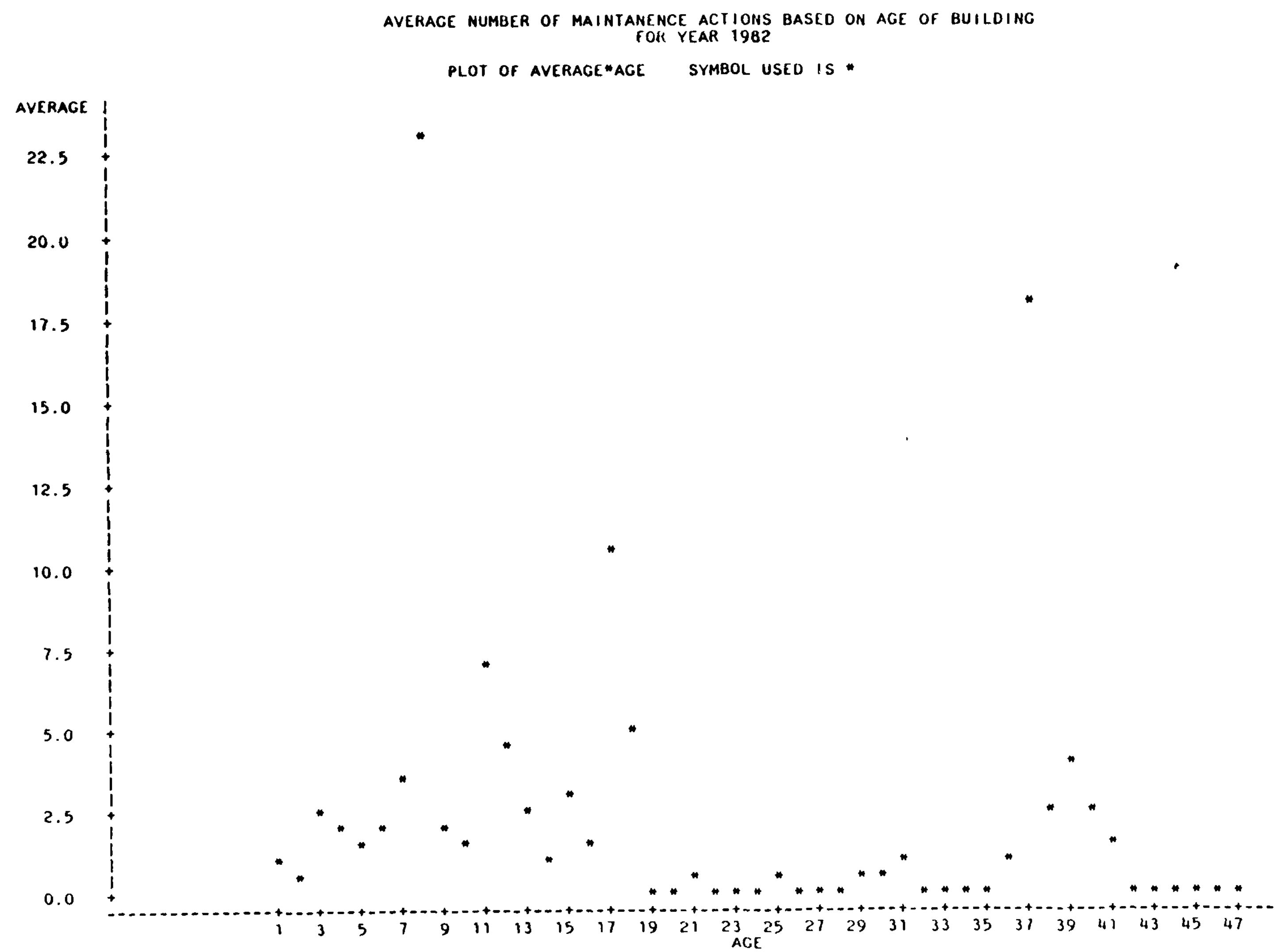

Figure 12. Average Number of Maintenance Actions based on age of Building a. 1982 Data

AVERAGE NUMBER OF MAINTANENCE ACTIONS BASED ON AGE OF BUILDING
FOR YEAR 1983

PLOT OF AVERAGE*AGE   SYMBOL USED IS *

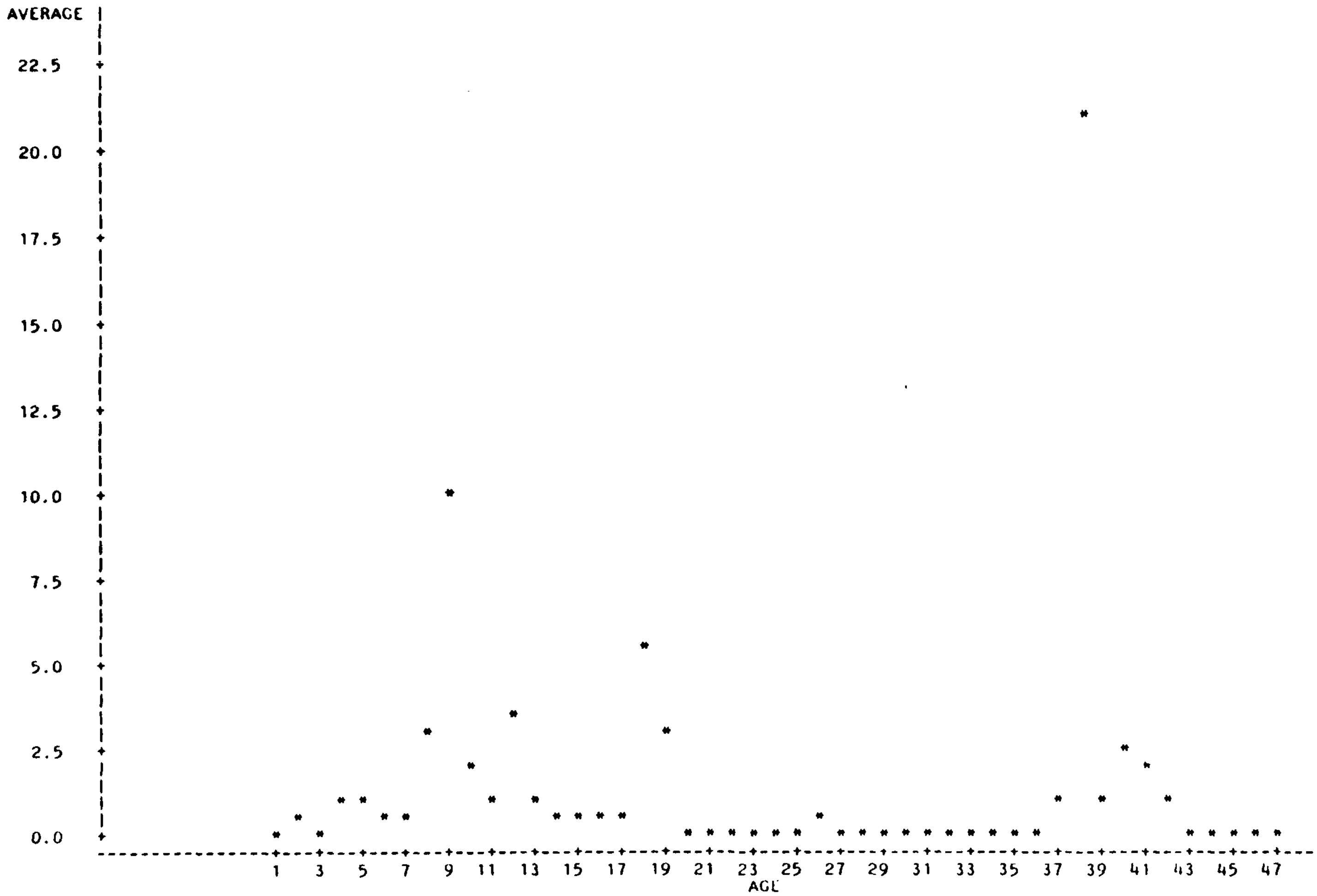

Figure 12 (Con't) b. 1983 Data

AVERAGE NUMBER OF MAINTANENCE ACTIONS BASED ON AGE OF BUILDING
FOR YEAR 1984

PLOT OF AVERAGE*AGE   SYMBOL USED IS *

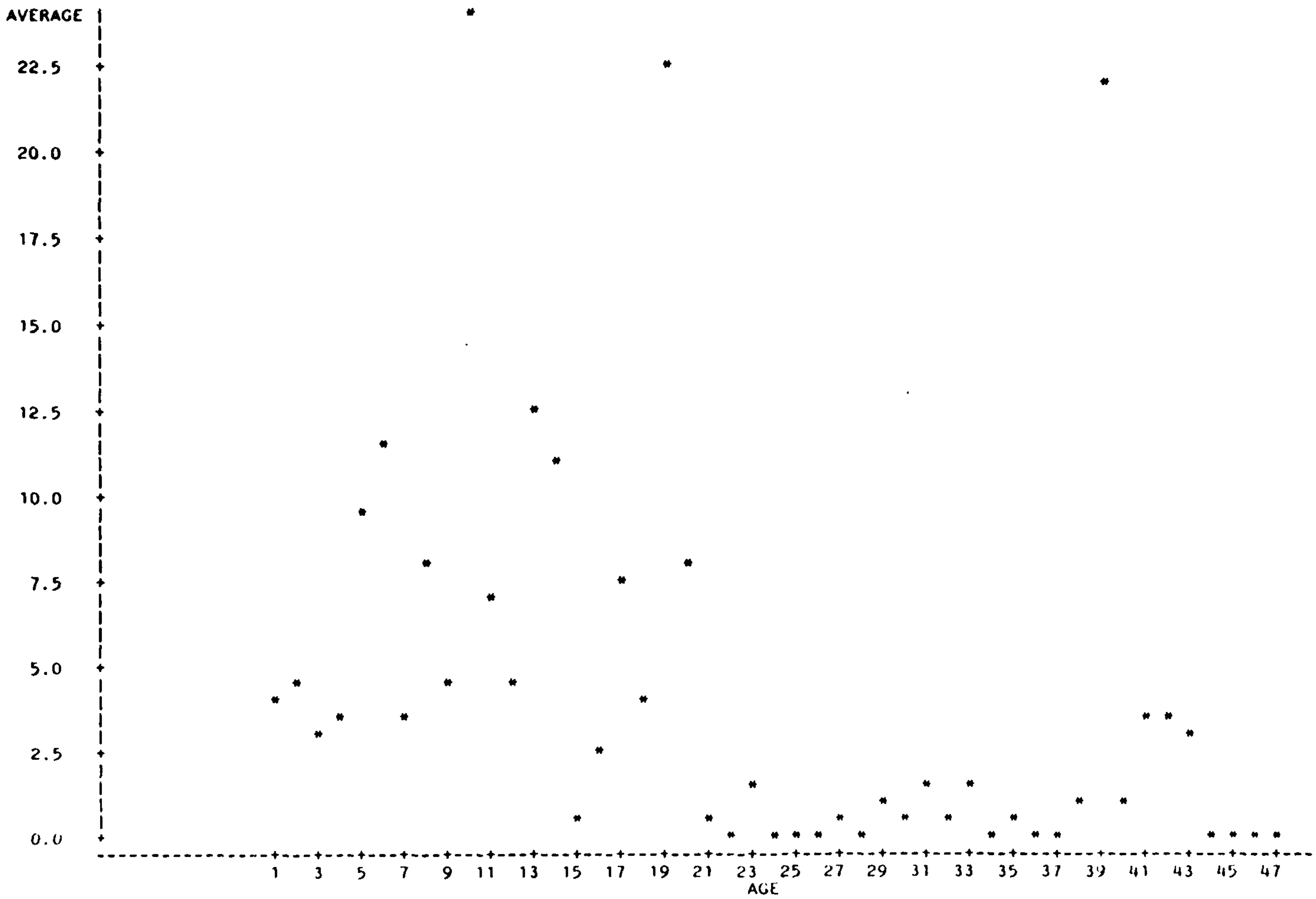

Figure 12 (Con't)   c. 1984 Data

AVERAGE NUMBER OF MAINTANENCE ACTIONS BASED ON AGE OF BUILDING
FOR YEAR 1985

PLOT OF AVERAGE*AGE   SYMBOL USED IS *

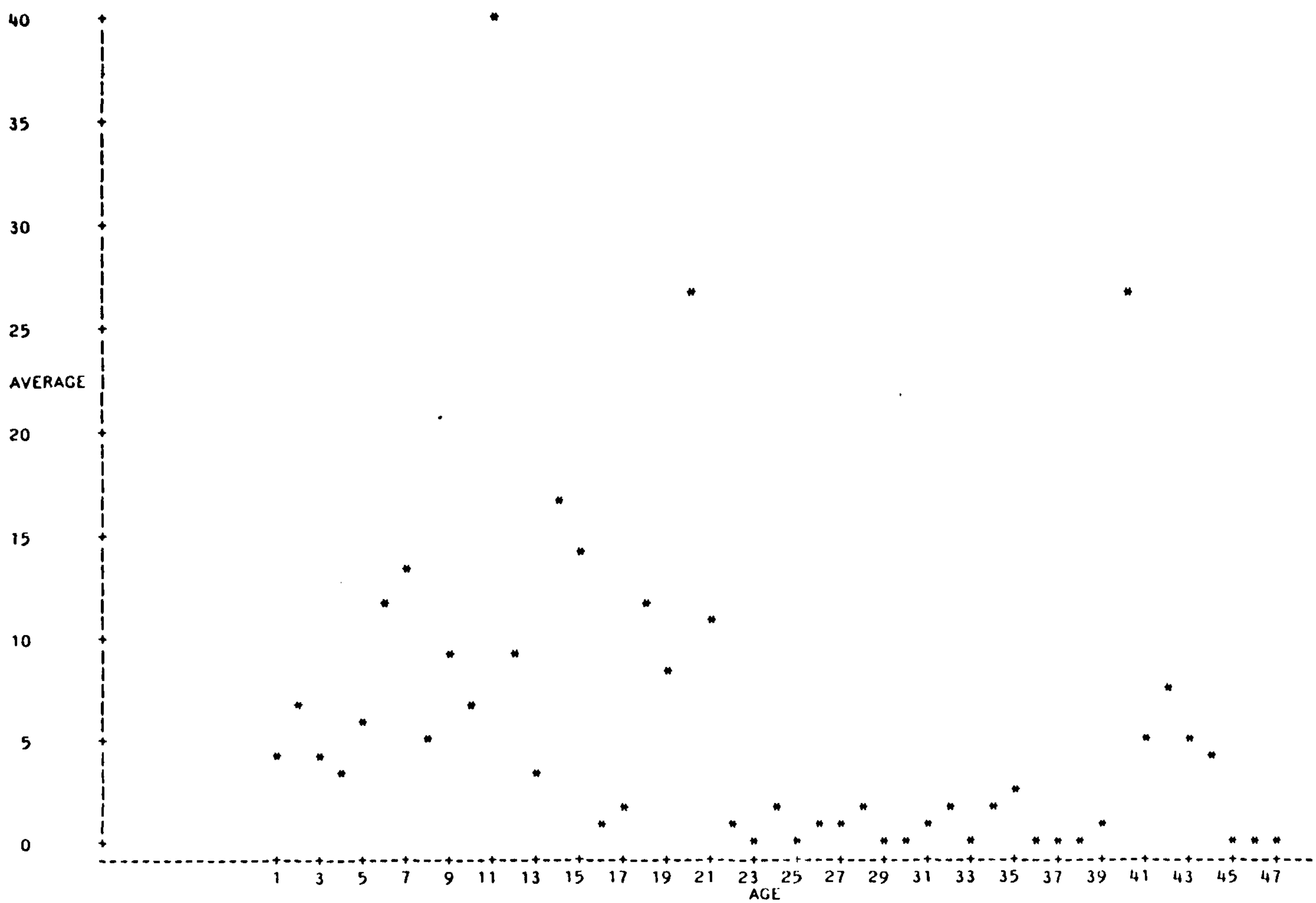

Figure 12 (Con't) d. 1985 Data

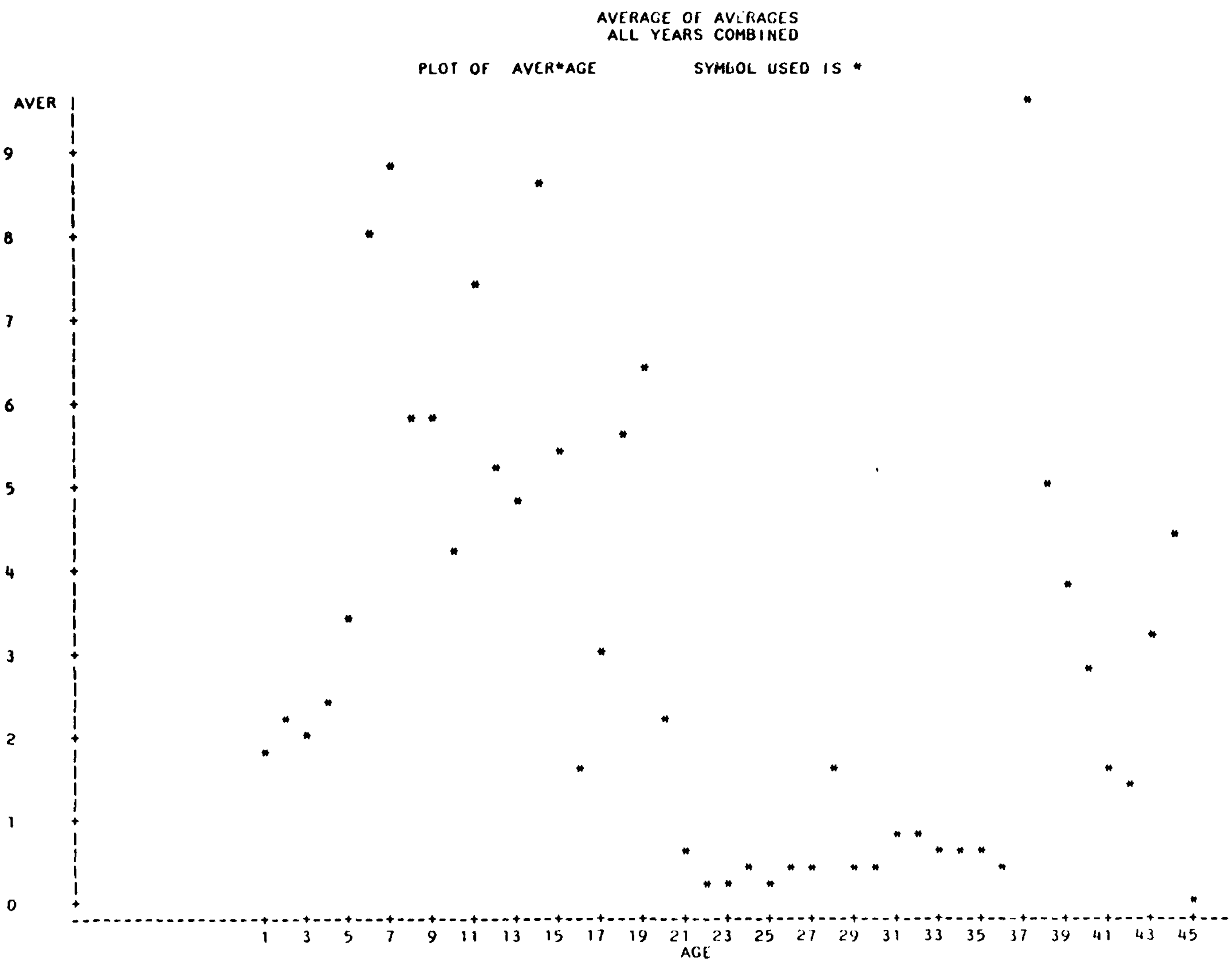

Figure 12 (Con't) e. All Data Combined

buildings built from 1960 to 1964. DEH personnel explained that these buildings have several avenues for maintenance (self-help, service orders, or preventative maintenance), and many times do not get entered into the IFS system due to this. This can account for some of the very low average values in those age groups.

B. REGRESSION ANALYSIS

The third step in analyzing the data was to check for correlation with a regression analysis. SAS provides the software for this, and the results are in Figure 13. While the intercept varied from 0 to almost 6 maintenance actions at age 1, the slope of the line was, in all cases, very near zero, or flat across the overall scope. This translates into claiming that maintenance does not vary over the life of a building. It is a safe assumption to claim that this is false. A building is certainly a deteriorating system. The regression of all the combined data has the same range of figures. Thus, the data must have some values that cause the regression to become flat.

C. REVISED DATA SET

Based on the knowledge gained from all the observations, it was decided to revise the data base by removing several sets of data that cause large distortions in either direction from the mean. The two main sets of data removed were the family housing units, approximately 1200 buildings from the total of 2550 buildings, and the three buildings previously identified as having large amounts of maintenance done each year. This modified database was then used in all the procedures previously discussed.

REGRESSION ANALYSIS FOR 1982 DATA

DEP VARIABLE: COUNT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	4.911549	4.911549	0.304	0.5813
ERROR	2518	40650.396	16.143922		
C TOTAL	2519	40655.308			
ROOT MSE		4.017950	R-SQUARE	0.0001	
DEP MEAN		1.130159	ADJ R-SQ	-0.0003	
C.V.		355.5209			

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	1.033954	0.191906	5.388	0.0001
AGE	1	0.003823303	0.006931609	0.552	0.5813
DURBIN-WATSON D			1.629		
(NUMBER OF OBS)			2520		
1ST ORDER AUTOCORRELATION			0.186		

Figure 13. Regression Analysis

a. 1982 Data

REGRESSION ANALYSIS FOR 1983 DATA

DEP VARIABLE: COUNT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	78.972493	78.972493	9.000	0.0027
ERROR	2532	22217.212	8.774570		
C TOTAL	2533	22296.185			
ROOT MSE		2.962190	R-SQUARE	0.0035	
DEP MEAN		0.577743	ADJ R-SQ	0.0031	
C.V.		512.7179			

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	0.183909	0.143862	1.278	0.2012
AGE	1	0.015134	0.005044509	3.000	0.0027
DURBIN-WATSON D			1.772		
(NUMBER OF OBS)			2534		
1ST ORDER AUTOCORRELATION			0.114		

Figure 13 (Con't)

b. 1983 Data

REGRESSION ANALYSIS FOR 1984 DATA

```
DEP VARIABLE: COUNT
                        SUM OF          MEAN
SOURCE      DF         SQUARES        SQUARE       F VALUE       PROB>F
MODEL        1        1575.957      1575.957        22.984       0.0001
ERROR     2539          174095     68.568297
C TOTAL   2540          175671
    ROOT MSE          8.280598      R-SQUARE        0.0090
    DEP MEAN          2.593861      ADJ R-SQ        0.0086
    C.V.              319.2383

                     PARAMETER      STANDARD    T FOR HO:
VARIABLE    DF        ESTIMATE         ERROR  PARAMETER=0   PROB > |T|

INTERCEP     1        4.403583      0.411681        10.697       0.0001
AGE          1       -0.067146      0.014006        -4.794       0.0001
DURBIN-WATSON D                  1.182
(NUMBER OF OBS)                   2541
1ST ORDER AUTOCORRELATION        0.409
```

Figure 13 (Con't)

c. 1984 Data

REGRESSION ANALYSIS FOR 1985 DATA

```
DEP VARIABLE: COUNT
                        SUM OF          MEAN
SOURCE      DF         SQUARES        SQUARE       F VALUE       PROB>F
MODEL        1        1917.247      1917.247        19.351       0.0001
ERROR     2542          251848     99.074886
C TOTAL   2543          253766
    ROOT MSE          9.953637      R-SQUARE        0.0076
    DEP MEAN          3.719340      ADJ R-SQ        0.0072
    C.V.              267.6184

                     PARAMETER      STANDARD    T FOR HO:
VARIABLE    DF        ESTIMATE         ERROR  PARAMETER=0   PROB > |T|

INTERCEP     1        5.780722      0.508458        11.369       0.0001
AGE          1       -0.073831      0.016784        -4.399       0.0001
DURBIN-WATSON D                  1.307
(NUMBER OF OBS)                   2544
1ST ORDER AUTOCORRELATION        0.346
```

Figure 13 (Con't)

d. 1985 Data

REGRESSION ANALYSIS FOR ALL DATA

DEP VARIABLE: COUNT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	707.670	707.670	14.146	0.0002
ERROR	10137	507129	50.027482		
C TOTAL	10138	507836			
ROOT MSE		7.073011	R-SQUARE	0.0014	
DEP MEAN		2.008581	ADJ R-SQ	0.0013	
C.V.		352.1397			

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	2.606322	0.173760	15.000	0.0001
AGE	1	-0.022541	0.005993192	-3.761	0.0002
DURBIN-WATSON D			1.256		
(NUMBER OF OBS)			10139		
1ST ORDER AUTOCORRELATION			0.372		

Figure 13 (Con't)

e. All Data Combined

The number of maintenance actions dropped by removing the high values, and the data is more consistent, Figure 14. There are several areas that are high, including the oldest buildings, which is expected. The standard means package, Figure 15, shows a smaller variance for each year and corresponding lower standard deviation and maximum value.

The average graphs, Figure 16, and Tables 3 and 4, again show the closer values but the graphs do show that the drop between ages 25-40 is still present, even after removing the family housing units. There are no outliers in this data set that would have an effect on the overall data.

This drop also causes the regression analysis to flatten out, Figure 17. The slope values are still near zero, but they are higher than with the previous database.

The revised database, now analyzed, will be the sole input into the Weibull Process model. This is because the adjusted file is most realistic of the overall data from Fort Wood.

D. WEIBULL PROCESS ANALYSIS RESULTS

1. Estimated Parameters: The modified procedure (Appendix I) can now estimate the $\hat{\beta}$ and $\hat{\theta}$ values of the Weibull Process. Each maintenance record is input into the procedure and is a single point on the time line of the entire system. That point is the age of the particular building when the maintenance was done.

The procedure computes the values for each year separately, and then combines the datasets for an overall estimation. The values are in Figure 18. The overall estimated values are the last line, even though the year of data is printed as 85.

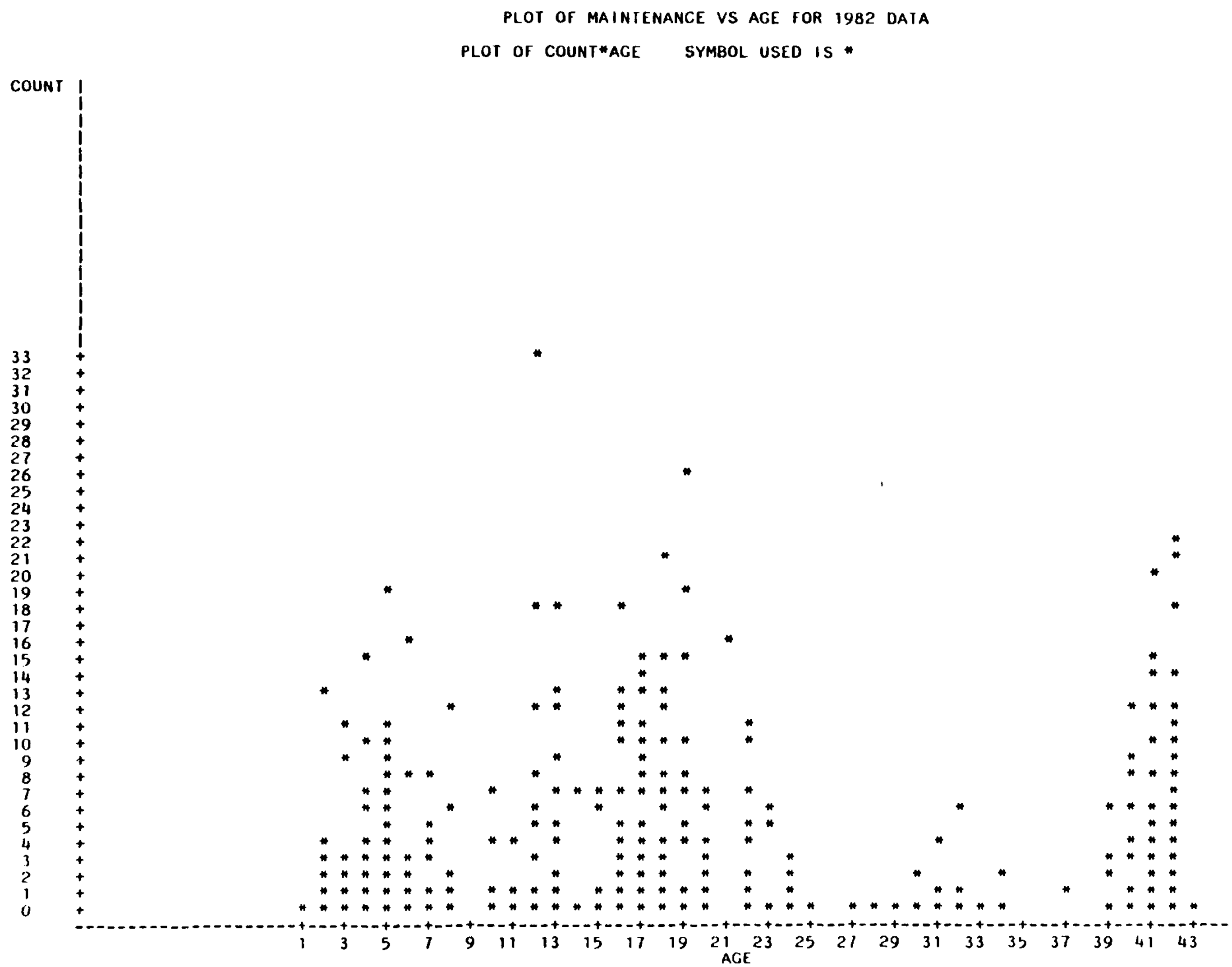

Figure 14. Plot of Maintenance vs Age Using the Revised Data Set a. 1982 Data

PLOT OF MAINTENANCE VS AGE FOR 1983 DATA

PLOT OF COUNT*AGE   SYMBOL USED IS *

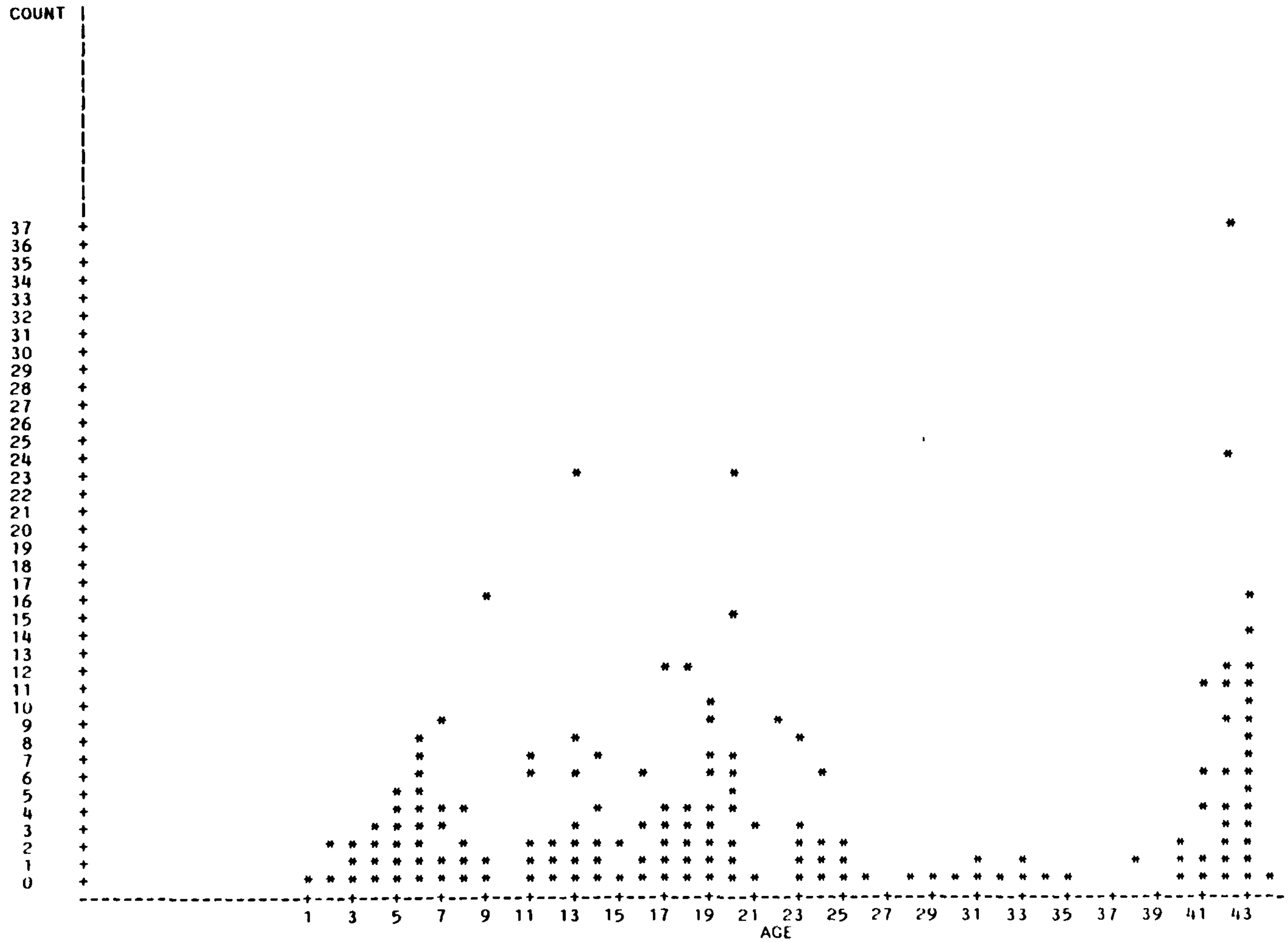

Figure 14 (Con't)   b. 1983 Data

PLOT OF MAINTENANCE VS AGE FOR 1984 DATA

PLOT OF COUNT*AGE   SYMBOL USED IS *

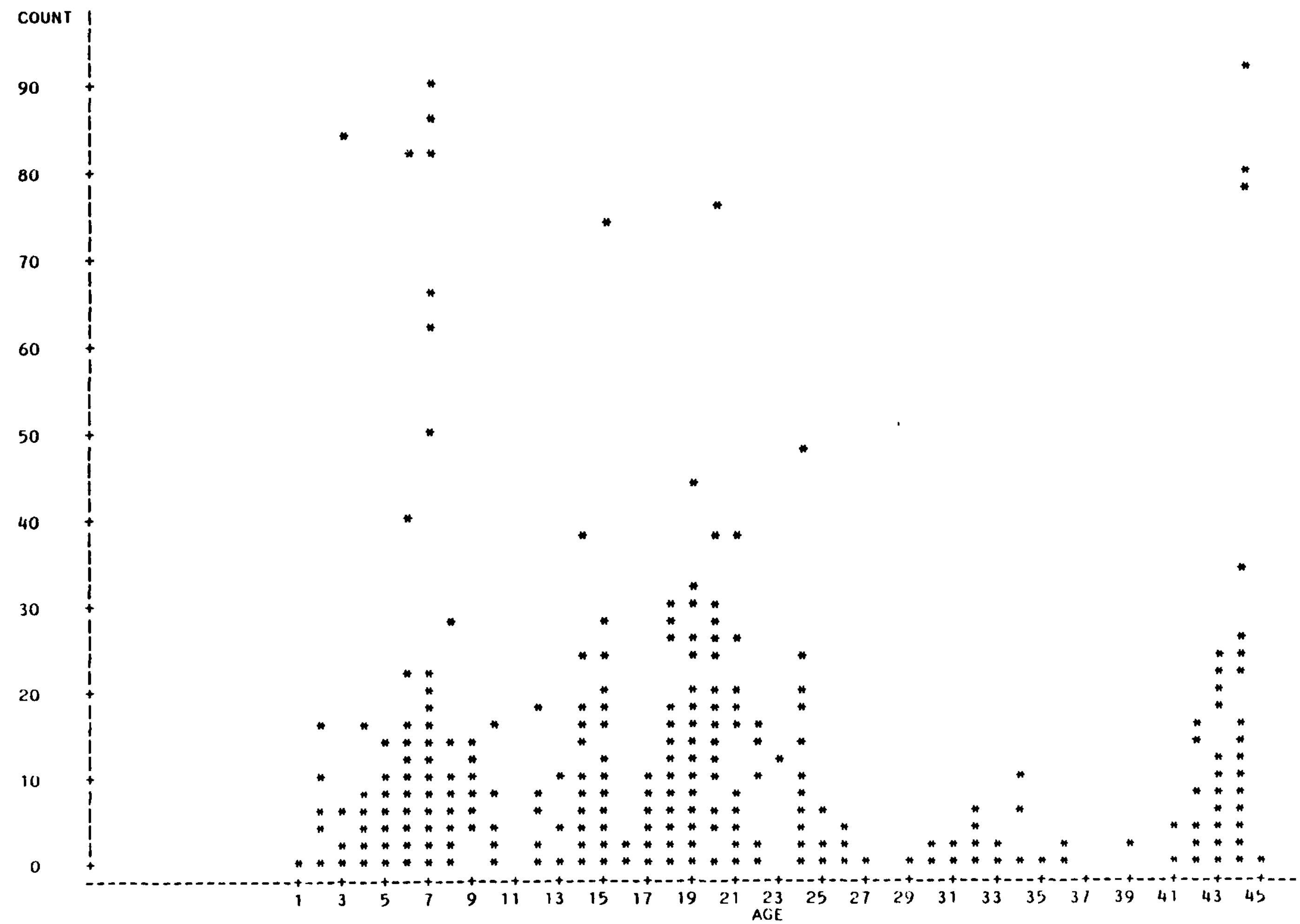

Figure 14 (Con't)   c. 1984 Data

PLOT OF MAINTENANCE VS AGE FOR 1985 DATA

PLOT OF COUNT*AGE   SYMBOL USED IS *

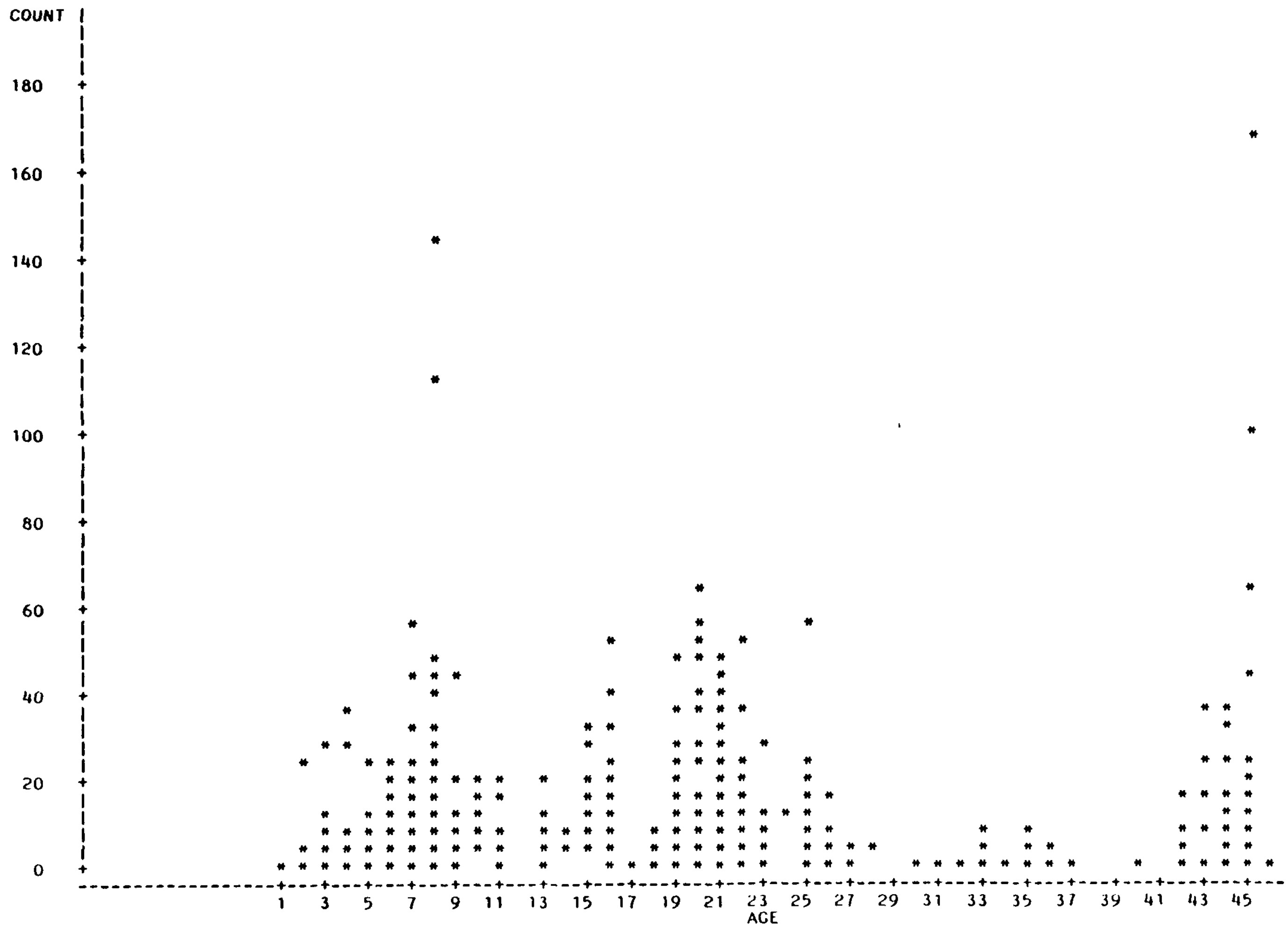

Figure 14 (Con't)   d. 1985 Data

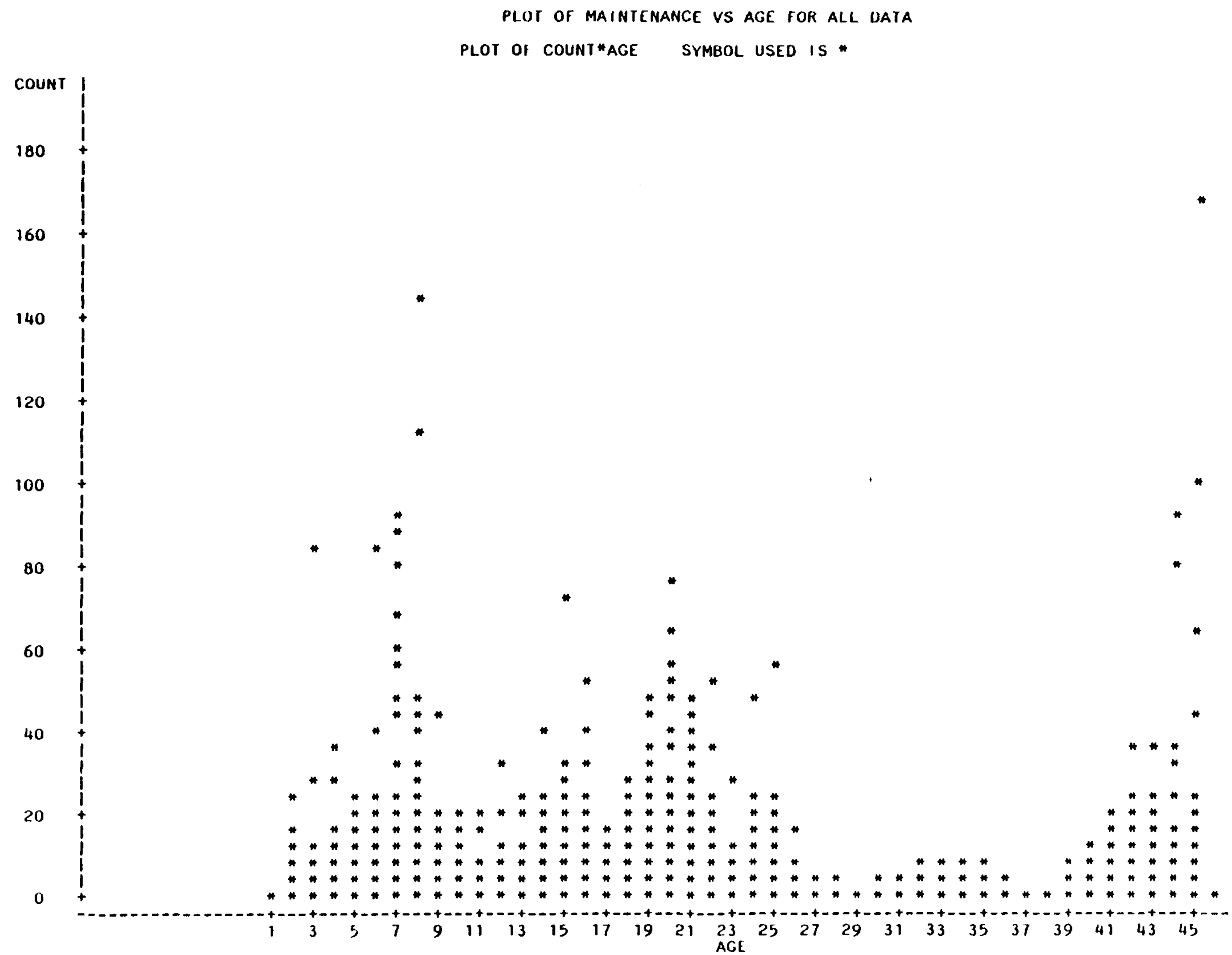

Figure 14 (Con't) e. All Data Combined

FT LEONARD WOOD BUILDING 1984 DATA
FAMILY HOUSING AND ADDITIONAL DATA REMOVED

SIMPLE MEAN OF DATA

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE
COUNT	1365	4.52673993	9.57453681	0	92.00000000	0.25915014	6179.0000000	91.67175513

FT LEONARD WOOD BUILDING 1984 DATA
FAMILY HOUSING AND ADDITIONAL DATA REMOVED

REQUESTED STATISTICS

VARIABLE	N MISSING	RANGE	UNCORRECTED SS	CORRECTED SS	SKEWNESS	KURTOSIS	T	PR>|T|
COUNT	0	92.0000000000	153011.000000	125040.273993	5.42809167778	37.9143664194	17.47	0.0001

Figure 15. Simple Mean and Statistics, Family Housing and Additional Data Removed

a. 1982 Data

FT LEONARD WOOD BUILDING 1985 DATA
FAMILY HOUSING AND ADDITIONAL DATA REMOVED

SIMPLE MEAN OF DATA

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE
COUNT	1368	6.35818713	11.32593816	0	168.00000000	0.30621830	8698.0000000	128.27687513

FT LEONARD WOOD BUILDING 1985 DATA
FAMILY HOUSING AND ADDITIONAL DATA REMOVED

REQUESTED STATISTICS

VARIABLE	N MISSING	RANGE	UNCORRECTED SS	CORRECTED SS	SKEWNESS	KURTOSIS	T	PR>|T|
COUNT	0	168.000000000	230658.000000	175354.488304	5.75217259421	56.4744500381	20.76	0.0001

Figure 15 (Con't)

b. 1983 Data

FT LEONARD WOOD BUILDING 1982 DATA
FAMILY HOUSING AND ADDITIONAL DATA REMOVED

SIMPLE MEAN OF DATA

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE
COUNT	1346	1.91233284	3.43691477	0	33.00000000	0.09367986	2574.0000000	11.81238310

FT LEONARD WOOD BUILDING 1982 DATA
FAMILY HOUSING AND ADDITIONAL DATA REMOVED

REQUESTED STATISTICS

VARIABLE	N MISSING	RANGE	UNCORRECTED SS	CORRECTED SS	SKEWNESS	KURTOSIS	T	PR>|T|
COUNT	0	33.0000000000	20810.0000000	15887.6552749	3.06461889782	12.9477159943	20.41	0.0001

Figure 15 (Con't)

c. 1984 Data

FT LEONARD WOOD BUILDING 1983 DATA
FAMILY HOUSING AND ADDITIONAL DATA REMOVED

SIMPLE MEAN OF DATA

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE
COUNT	1358	0.94182622	2.46454659	0	37.00000000	0.06687860	1279.0000000	6.07398988

FT LEONARD WOOD BUILDING 1983 DATA
FAMILY HOUSING AND ADDITIONAL DATA REMOVED

REQUESTED STATISTICS

VARIABLE	N MISSING	RANGE	UNCORRECTED SS	CORRECTED SS	SKEWNESS	KURTOSIS	T	PR>|T|
COUNT	0	37.0000000000	9447.00000000	8242.40427099	5.91532732470	54.5573914064	14.08	0.0001

Figure 15 (Con't)

d. 1985 Data

FT LEONARD WOOD BUILDING ALL DATA
FAMILY HOUSING AND ADDITIONAL DATA REMOVED

SIMPLE MEAN OF DATA

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE
COUNT	5437	3.44491447	8.01721327	0	168.00000000	0.10872859	18730.000000	64.27570859

FT LEONARD WOOD BUILDING ALL DATA
FAMILY HOUSING AND ADDITIONAL DATA REMOVED

REQUESTED STATISTICS

VARIABLE	N MISSING	RANGE	UNCORRECTED SS	CORRECTED SS	SKEWNESS	KURTOSIS	T	PR>|T|
COUNT	0	168.000000000	413926.000000	349402.751885	7.14103088749	85.0033386154	31.68	0.0001

Figure 15 (Con't)

e. All Data Combined

Table III

Buildings and Maintenance for all Data, Family and Additional Data Removed

OBS	AGE	BLDG82	MAINT82	AVE82	BLDG83	MAINT83	AVE83	BLDG84	MAINT84	AVE84	BLDG85	MAINT85	AVE85
1	1	23	23	1.0000	20	2	0.10000	12	49	4.0833	7	31	4.4286
2	2	42	31	0.7381	23	6	0.26087	20	92	4.6000	12	65	5.4167
3	3	28	67	2.3929	42	9	0.21429	23	70	3.0435	20	77	3.8500
4	4	70	146	2.0857	28	24	0.85714	42	151	3.5952	23	85	3.6957
5	5	34	45	1.3235	70	70	1.00000	28	266	9.5000	42	230	5.4762
6	6	13	24	1.8462	34	21	0.61765	70	816	11.6571	28	318	11.3571
7	7	6	22	3.6667	13	8	0.61538	34	112	3.2941	70	956	13.6571
8	8	0	0	0.0000	6	18	3.00000	13	105	8.0769	34	170	5.0000
9	9	6	14	2.3333	0	0	0.00000	6	28	4.6667	13	122	9.3846
10	10	3	5	1.6667	6	16	2.66667	0	0	0.0000	6	41	6.8333
11	11	14	101	7.2143	3	3	1.00000	6	34	5.6667	0	0	0.0000
12	12	25	93	3.7200	14	49	3.50000	3	14	4.6667	6	42	7.0000
13	13	3	7	2.3333	25	19	0.76000	14	188	13.4286	3	11	3.6667
14	14	21	22	1.0476	3	2	0.66667	25	279	11.1600	14	250	17.8571
15	15	42	120	2.8571	21	10	0.47619	3	1	0.3333	25	318	12.7200
16	16	155	261	1.6839	42	30	0.71429	21	56	2.6667	3	2	0.6667
17	17	29	174	6.0000	155	69	0.44516	42	321	7.6429	21	40	1.9048
18	18	25	123	4.9200	29	55	1.89655	155	616	3.9742	42	487	11.5952
19	19	14	25	1.7857	25	73	2.92000	29	492	16.9655	155	1177	7.5935
20	20	1	16	16.0000	14	3	0.21429	25	202	8.0800	29	594	20.4828
21	21	21	66	3.1429	1	9	9.00000	14	42	3.0000	25	269	10.7600
22	22	6	11	1.8333	21	23	1.09524	1	12	12.0000	14	58	4.1429
23	23	8	7	0.8750	6	9	1.50000	21	211	10.0476	1	10	10.0000
24	24	1	0	0.0000	8	3	0.37500	6	8	1.3333	21	239	11.3810
25	25	0	0	0.0000	1	0	0.00000	8	6	0.7500	6	23	3.8333
26	26	1	0	0.0000	0	0	0.00000	1	0	0.0000	8	6	0.7500
27	27	2	0	0.0000	1	0	0.00000	0	0	0.0000	1	2	2.0000
28	28	3	0	0.0000	2	0	0.00000	1	0	0.0000	0	0	0.0000
29	29	19	8	0.4211	3	0	0.00000	2	2	1.0000	1	0	0.0000
30	30	19	11	0.5789	19	2	0.10526	3	1	0.3333	2	0	0.0000
31	31	9	8	0.8889	19	0	0.00000	19	30	1.5789	3	2	0.6667
32	32	2	0	0.0000	9	1	0.11111	19	5	0.2632	19	37	1.9474
33	33	11	2	0.1818	2	0	0.00000	9	14	1.5556	19	6	0.3158
34	34	0	0	0.0000	11	0	0.00000	2	0	0.0000	9	15	1.6667
35	35	0	0	0.0000	0	0	0.00000	11	3	0.2727	2	5	2.5000
36	36	1	1	1.0000	0	0	0.00000	0	0	0.0000	11	4	0.3636
37	37	0	0	0.0000	1	1	1.00000	0	0	0.0000	0	0	0.0000
38	38	5	13	2.6000	0	0	0.00000	1	1	1.0000	0	0	0.0000
39	39	12	45	3.7500	5	4	0.80000	0	0	0.0000	1	1	1.0000
40	40	80	202	2.5250	12	30	2.50000	5	6	1.2000	0	0	0.0000
41	41	571	881	1.5429	80	151	1.88750	12	44	3.6667	5	27	5.4000
42	42	1	0	0.0000	571	566	0.99124	80	274	3.4250	12	88	7.3333
43	43	0	0	0.0000	1	0	0.00000	571	1688	2.9562	80	406	5.0750
44	44	0	0	0.0000	0	0	0.00000	1	0	0.0000	571		4.3520
45	45	0	0	0.0000	0	0	0.00000	0	0	0.0000	1		0.0000
46	46	0	0	0.0000	0	0	0.00000	0	0	0.0000	0	0	0.0000

Table IV

Buildings and Maintenance for all Data, Totals

OBS	TOTBLDG	TOTMAINT	AAVER
1	62	105	1.6935
2	97	194	2.0000
3	113	223	1.9735
4	163	406	2.4908
5	174	611	3.5115
6	145	1179	8.1310
7	123	1098	8.9268
8	53	293	5.5283
9	25	164	6.5600
10	15	62	4.1333
11	23	138	6.0000
12	48	198	4.1250
13	45	225	5.0000
14	63	553	8.7778
15	91	449	4.9341
16	221	349	1.5792
17	247	604	2.4453
18	251	1281	5.1036
19	223	1767	7.9238
20	69	815	11.8116
21	61	386	6.3279
22	42	104	2.4762
23	36	237	6.5833
24	36	250	6.9444
25	15	29	1.9333
26	10	6	0.6000
27	4	2	0.5000
28	6	0	0.0000
29	25	10	0.4000
30	43	14	0.3256
31	50	40	0.8000
32	49	43	0.8776
33	41	22	0.5366
34	22	15	0.6818
35	13	8	0.6154
36	12	5	0.4167
37	1	1	1.0000
38	6	14	2.3333
39	18	50	2.7778
40	97	238	2.4536
41	668	1103	1.6512
42	664	928	1.3976
43	652	2094	3.2117
44	572	2485	4.3444
45	1	0	0.0000
46	0	0	.

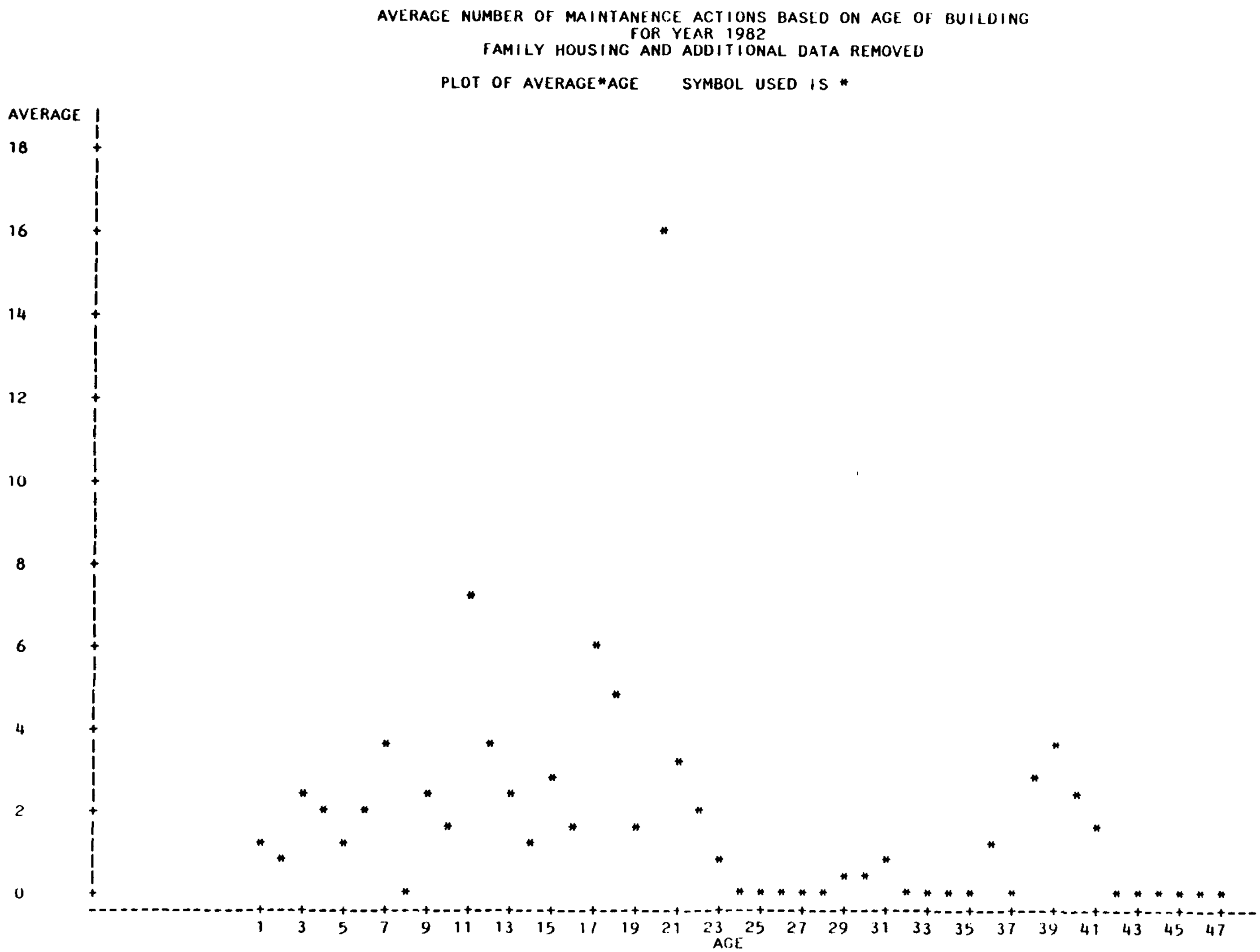

Figure 16. Average Number of Maintenance Actions based on Age of Building, Family Housing and Additional Data Removed a. 1982 Data

AVERAGE NUMBER OF MAINTANENCE ACTIONS BASED ON AGE OF BUILDING
FOR YEAR 1983
FAMILY HOUSING AND ADDITIONAL DATA REMOVED

PLOT OF AVERAGE*AGE   SYMBOL USED IS *

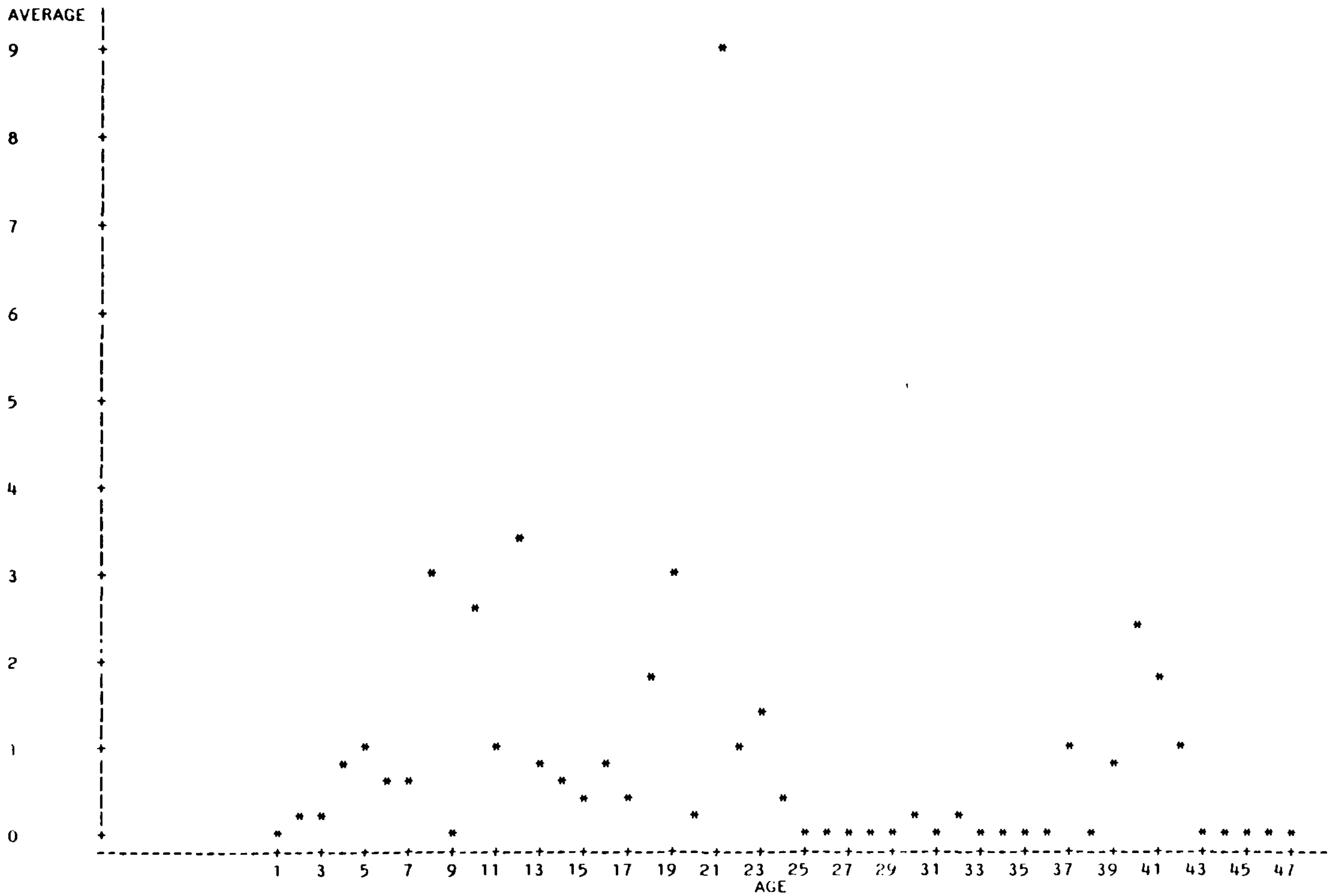

Figure 16 (Con't) b. 1983 Data

AVERAGE NUMBER OF MAINTANENCE ACTIONS BASED ON AGE OF BUILDING
FOR YEAR 1984
FAMILY HOUSING AND ADDITIONAL DATA REMOVED

PLOT OF AVERAGE*AGE   SYMBOL USED IS *

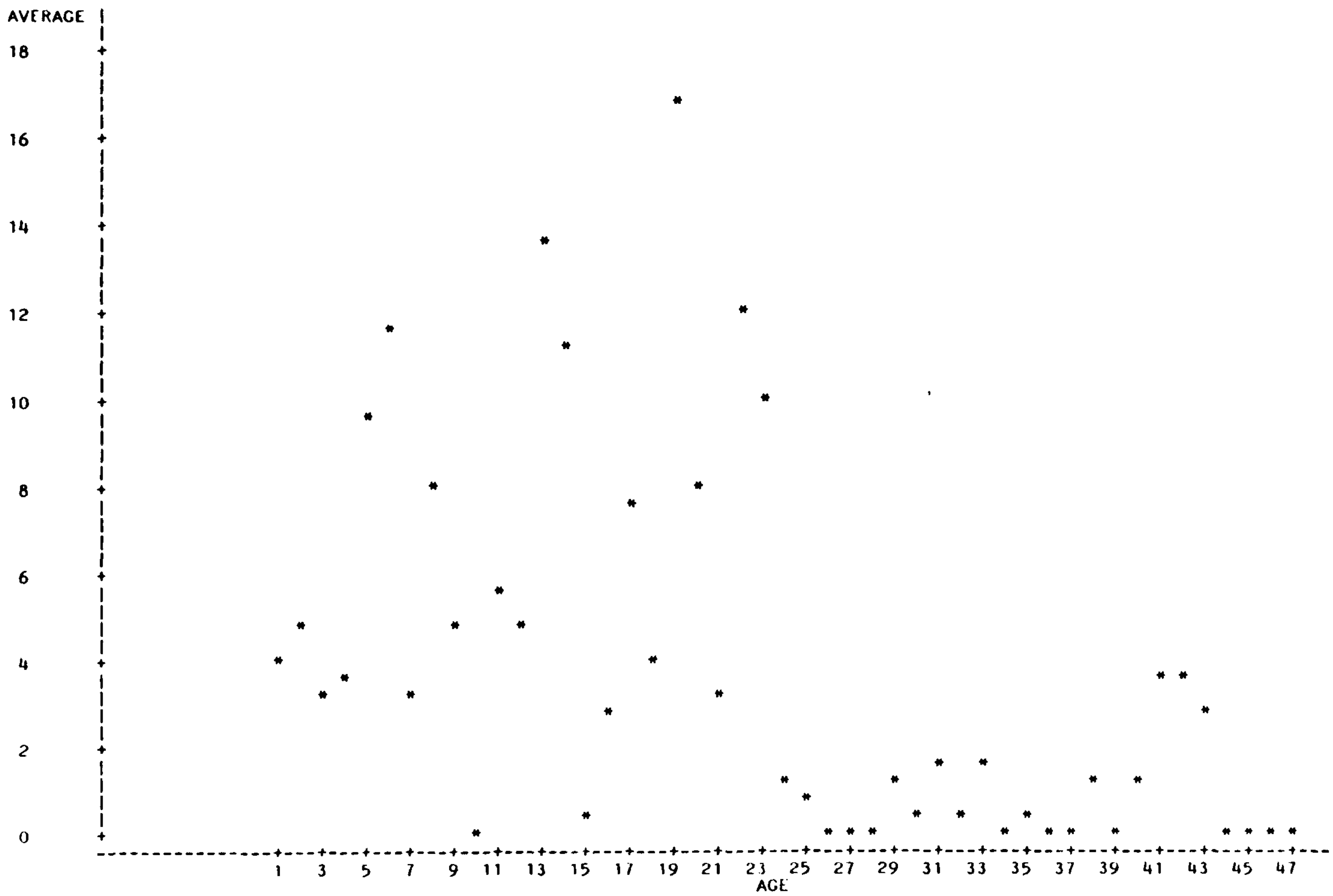

Figure 16 (Con't) c. 1984 Data

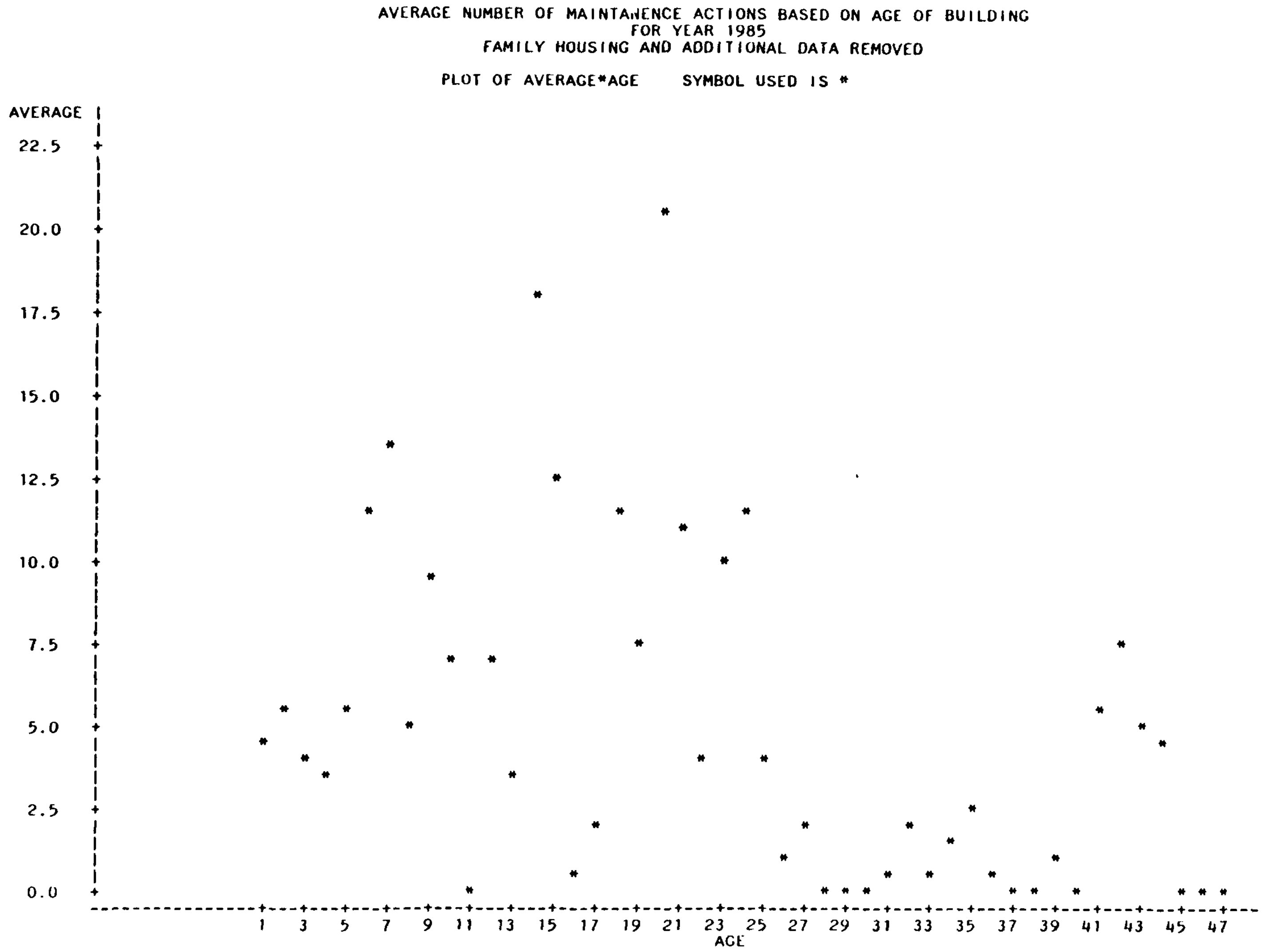

Figure 16 (Con't) d. 1985 Data

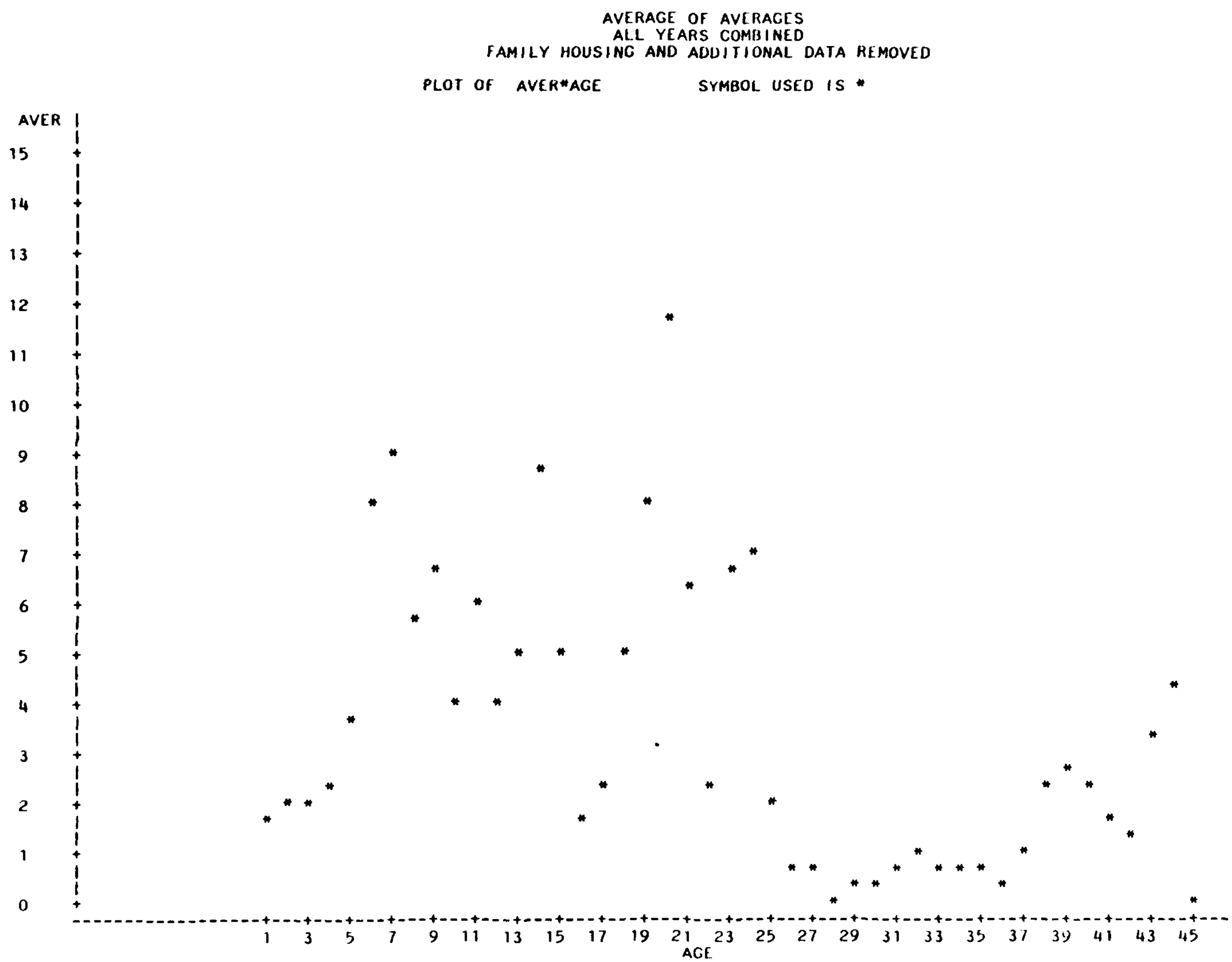

Figure 16 (Con't) e. All Data Combined

REGRESSION ANALYSIS FOR 1982 DATA
FAMILY HOUSING AND ADDITIONAL DATA REMOVED

DEP VARIABLE: COUNT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	43.163963	43.163963	3.661	0.0559
ERROR	1344	15844.491	11.789056		
C TOTAL	1345	15887.655			
ROOT MSE		3.433519	R-SQUARE	0.0027	
DEP MEAN		1.912333	ADJ R-SQ	0.0020	
C.V.		179.5461			

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	2.240064	0.195177	11.477	0.0001
AGE	1	-0.011783	0.006158179	-1.913	0.0559
DURBIN-WATSON D			1.385		
(NUMBER OF OBS)			1346		
1ST ORDER AUTOCORRELATION			0.307		

Figure 17. Regression Analysis, Family Housing and Additional Data Removed

a. 1982 Data

REGRESSION ANALYSIS FOR 1983 DATA
FAMILY HOUSING AND ADDITIONAL DATA REMOVED

DEP VARIABLE: COUNT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	26.763494	26.763494	4.417	0.0358
ERROR	1356	8215.641	6.058732		
C TOTAL	1357	8242.404			
ROOT MSE		2.461449	R-SQUARE	0.0032	
DEP MEAN		0.941826	ADJ R-SQ	0.0025	
C.V.		261.3486			

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > |T|
INTERCEP	1	0.680601	0.141101	4.824	0.0001
AGE	1	0.009144305	0.00435081	2.102	0.0358
DURBIN-WATSON D			1.556		
(NUMBER OF OBS)			1358		
1ST ORDER AUTOCORRELATION			0.222		

Figure 17 (Con't)

b. 1983 Data

```
                 REGRESSION ANALYSIS FOR 1984 DATA
             FAMILY HOUSING AND ADDITIONAL DATA REMOVED

DEP VARIABLE: COUNT
                        SUM OF          MEAN
SOURCE      DF         SQUARES        SQUARE       F VALUE       PROB>F
MODEL        1        3879.520      3879.520        43.643       0.0001
ERROR     1363          121161     88.892703
C TOTAL   1364          125040
    ROOT MSE          9.428293      R-SQUARE        0.0310
    DEP MEAN          4.526740      ADJ R-SQ        0.0303
    C.V.                208.28

                     PARAMETER      STANDARD    T FOR HO:
VARIABLE    DF        ESTIMATE         ERROR  PARAMETER=0    PROB > |T|

INTERCEP     1        7.737417      0.548930        14.095       0.0001
AGE          1       -0.109131      0.016519        -6.606       0.0001
DURBIN-WATSON D                  1.097
(NUMBER OF OBS)                   1365
1ST ORDER AUTOCORRELATION        0.451
```

Figure 17 (Con't)

c. 1984 Data

```
                 REGRESSION ANALYSIS FOR 1985 DATA
             FAMILY HOUSING AND ADDITIONAL DATA REMOVED

DEP VARIABLE: COUNT
                        SUM OF          MEAN
SOURCE      DF         SQUARES        SQUARE       F VALUE       PROB>F
MODEL        1        5298.883      5298.883        42.564       0.0001
ERROR     1366          170056       124.492
C TOTAL   1367          175354
    ROOT MSE         11.157583      R-SQUARE        0.0302
    DEP MEAN          6.358187      ADJ R-SQ        0.0295
    C.V.              175.4837

                     PARAMETER      STANDARD    T FOR HO:
VARIABLE    DF        ESTIMATE         ERROR  PARAMETER=0    PROB > |T|

INTERCEP     1       10.214512      0.663616        15.392       0.0001
AGE          1       -0.127037      0.019472        -6.524       0.0001
DURBIN-WATSON D                  1.394
(NUMBER OF OBS)                   1368
1ST ORDER AUTOCORRELATION        0.303
```

Figure 17 (Con't)

d. 1985 Data

REGRESSION ANALYSIS FOR ALL DATA
FAMILY HOUSING AND ADDITIONAL DATA REMOVED

DEP VARIABLE: COUNT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	3590.098	3590.098	56.424	0.0001
ERROR	5435	345813	63.626983		
C TOTAL	5436	349403			
ROOT MSE		7.976652	R-SQUARE	0.0103	
DEP MEAN		3.444914	ADJ R-SQ	0.0101	
C.V.		231.5486			

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	4.977194	0.230898	21.556	0.0001
AGE	1	-0.052756	0.007023257	-7.512	0.0001

DURBIN-WATSON D 1.241
(NUMBER OF OBS) 5437
1ST ORDER AUTOCORRELATION 0.379

Figure 17 (Con't)

e. All Data Combined

WEIBULL PARAMETERS

OBS	YEAR	KOUNT	BETAHAT	THETAHAT
1	82	2574	1.40343	0.159687
2	83	1279	1.86433	0.948363
3	84	6179	1.10679	0.016907
4	85	8698	1.23925	0.030471
5	85	18730	1.20933	0.013483

Figure 18. Weibull Process Estimation Values

The β values range from 1.1 to 1.86. The final estimation was 1.21. As stated before, a β value of 1.0 indicates that the system is in a random maintenance phase (Figure 3b) and the number of maintenance actions will not be increasing or decreasing very much.

2. Goodness-of-fit Test: The values computed for β are then used in the goodness-of- fit test. These results are printed in Figure 19. The figure shows the Chi-squared values are 3345 and higher with 42 degrees of freedom. These values indicate that the assumption of the data being a Weibull Process is not correct. Therefore it can be concluded that this data does not provide a good estimate of future data using the Weibull Process function.

Further evidence of not fitting the Weibull Process is seen when the estimated $\hat{\beta}$ value is used in the c.d.f:

$$F(x) = \left(\frac{x}{t}\right)^{\hat{\beta}}$$

and used to plot the trend graph (Figure 20). The actual data from Fort Leonard Wood is plotted with the estimated curve to compare the two lines. During the first 20 years, the graphs seem to follow close together, then they diverge and the deviation is much greater.

CHI SQUARED GOODNESS OF FIT TEST
PER BUILDING

OBS	YEAR	BETAHAT	CHI	DF
1	82	1.40343	3602.88	41
1	83	1.86433	3345.43	42
1	84	1.10679	7464.13	43
1	85	1.23925	11320.4	44
1	85	1.20933	19700	44

Figure 19. Chi Squared Test Results

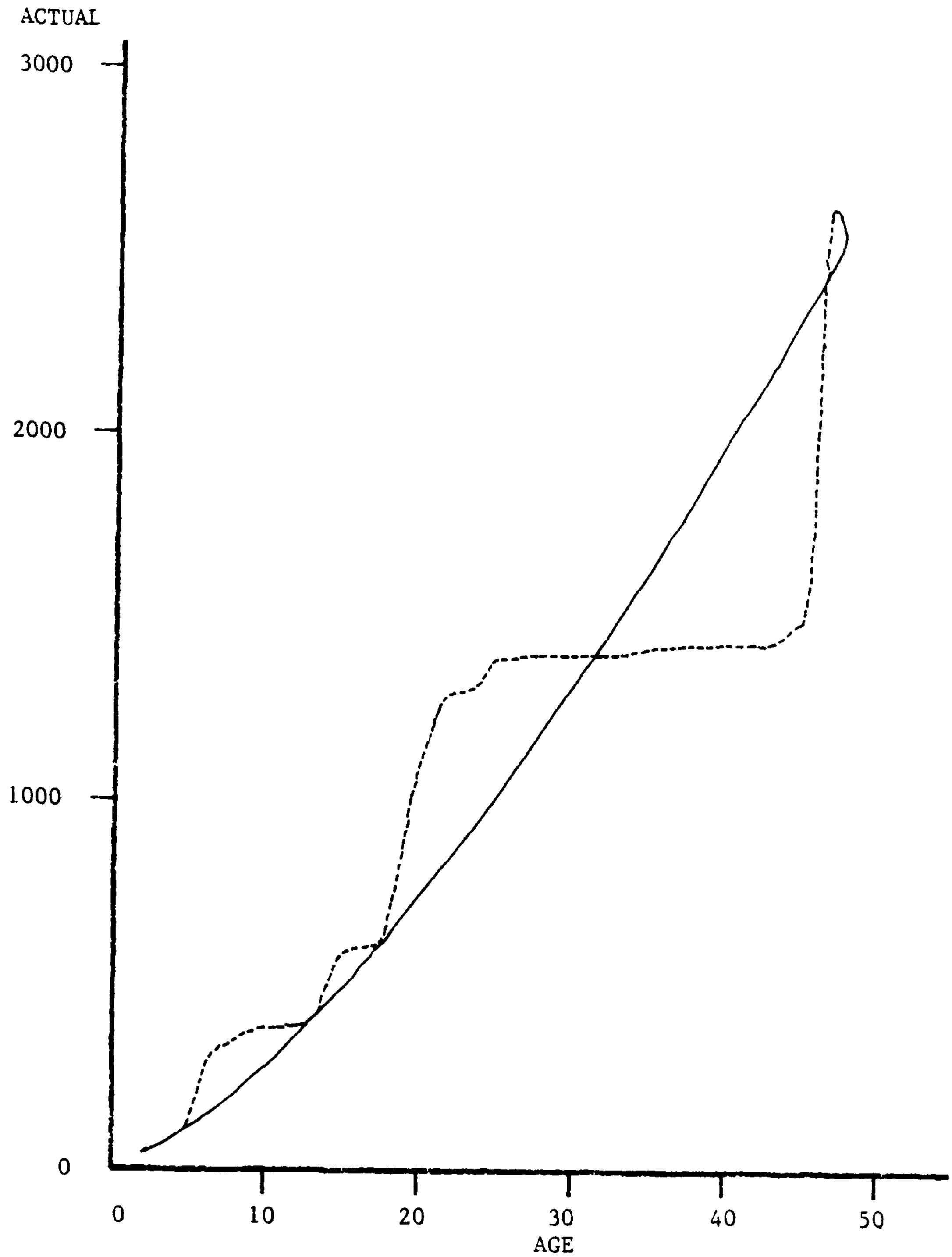

Figure 20. Expected and Actual Values using the Estimated Parameters

a. 1982 Data

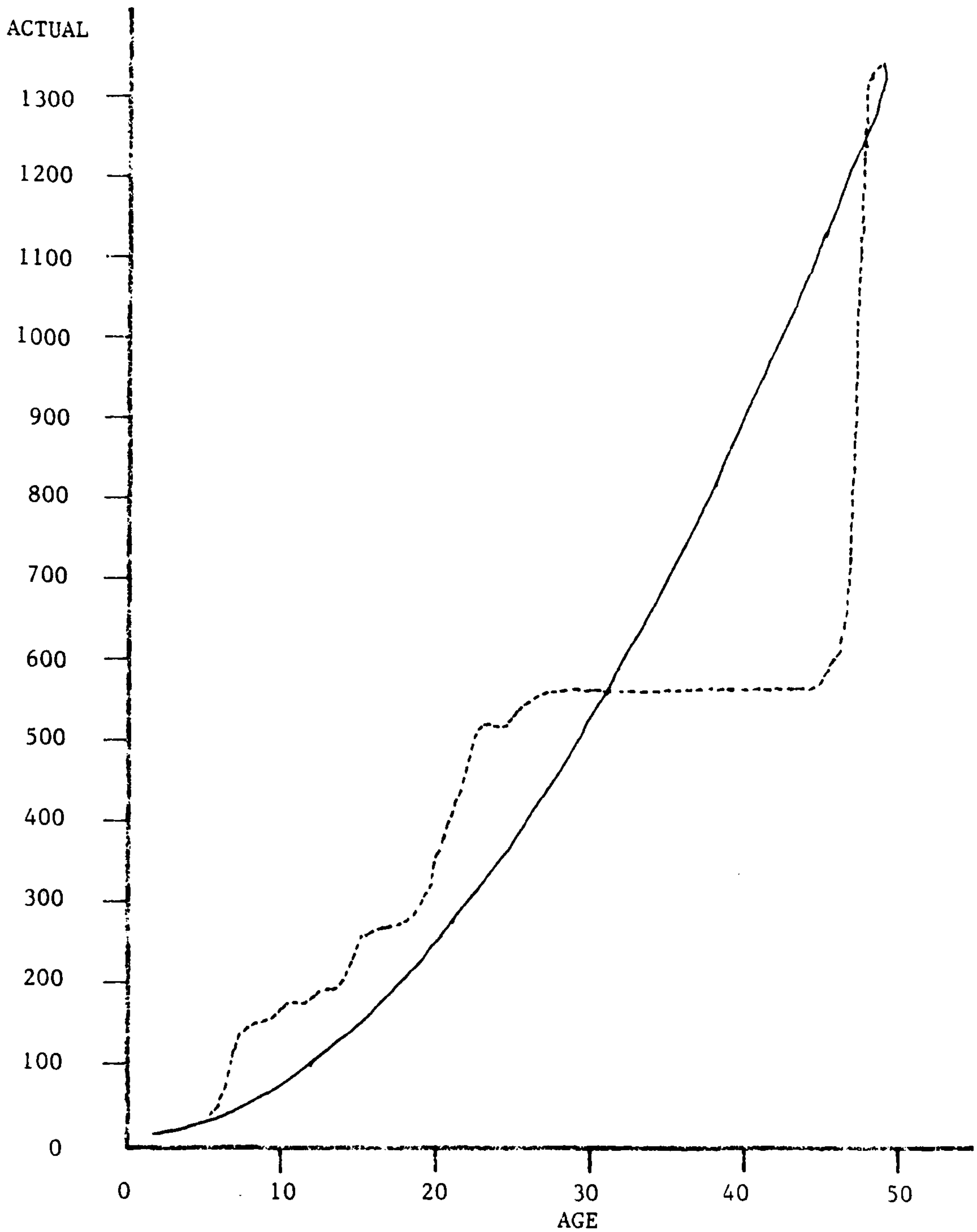

Figure 20 (Con't)

b. 1983 Data

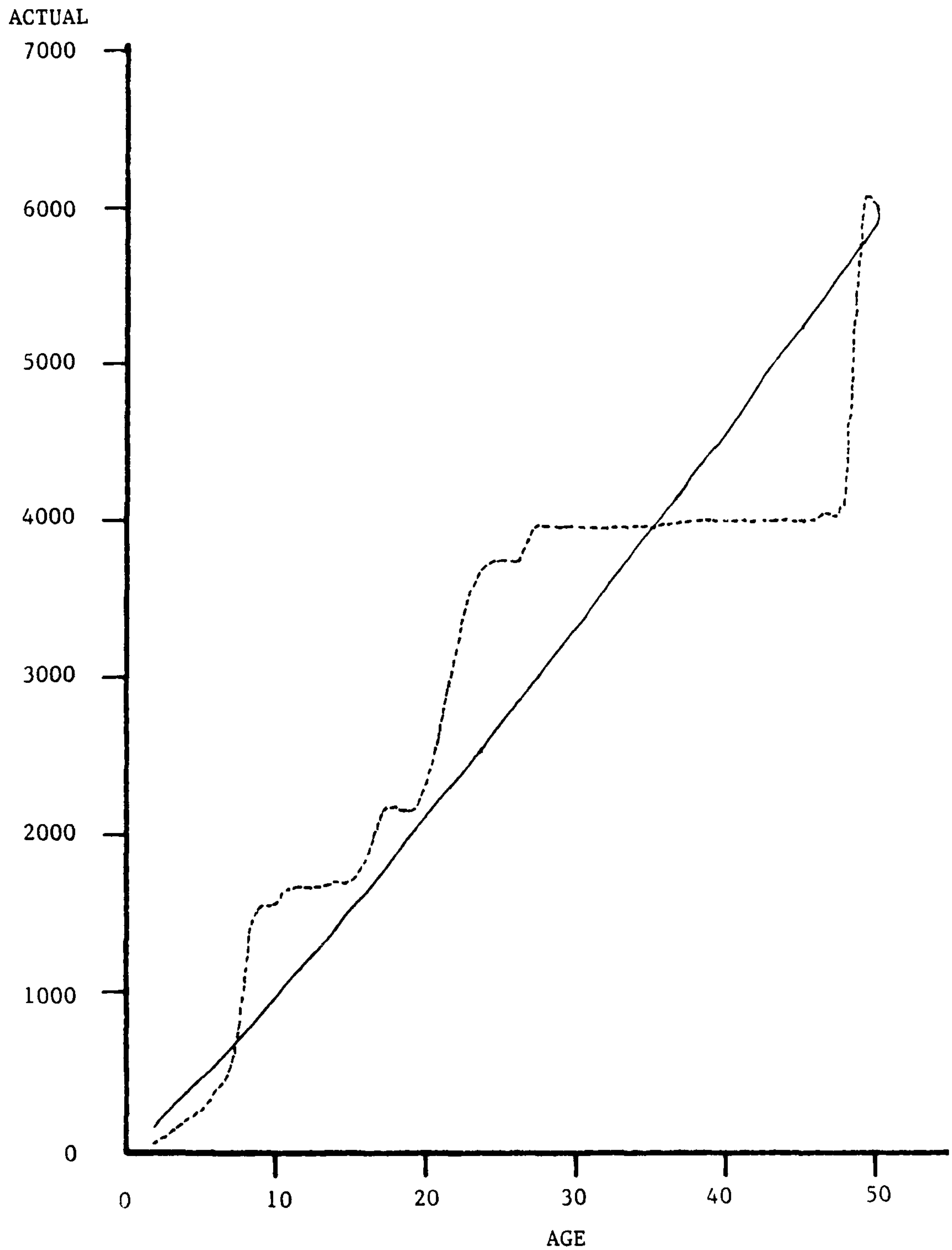

Figure 20 (Con't)

c. 1984 Data

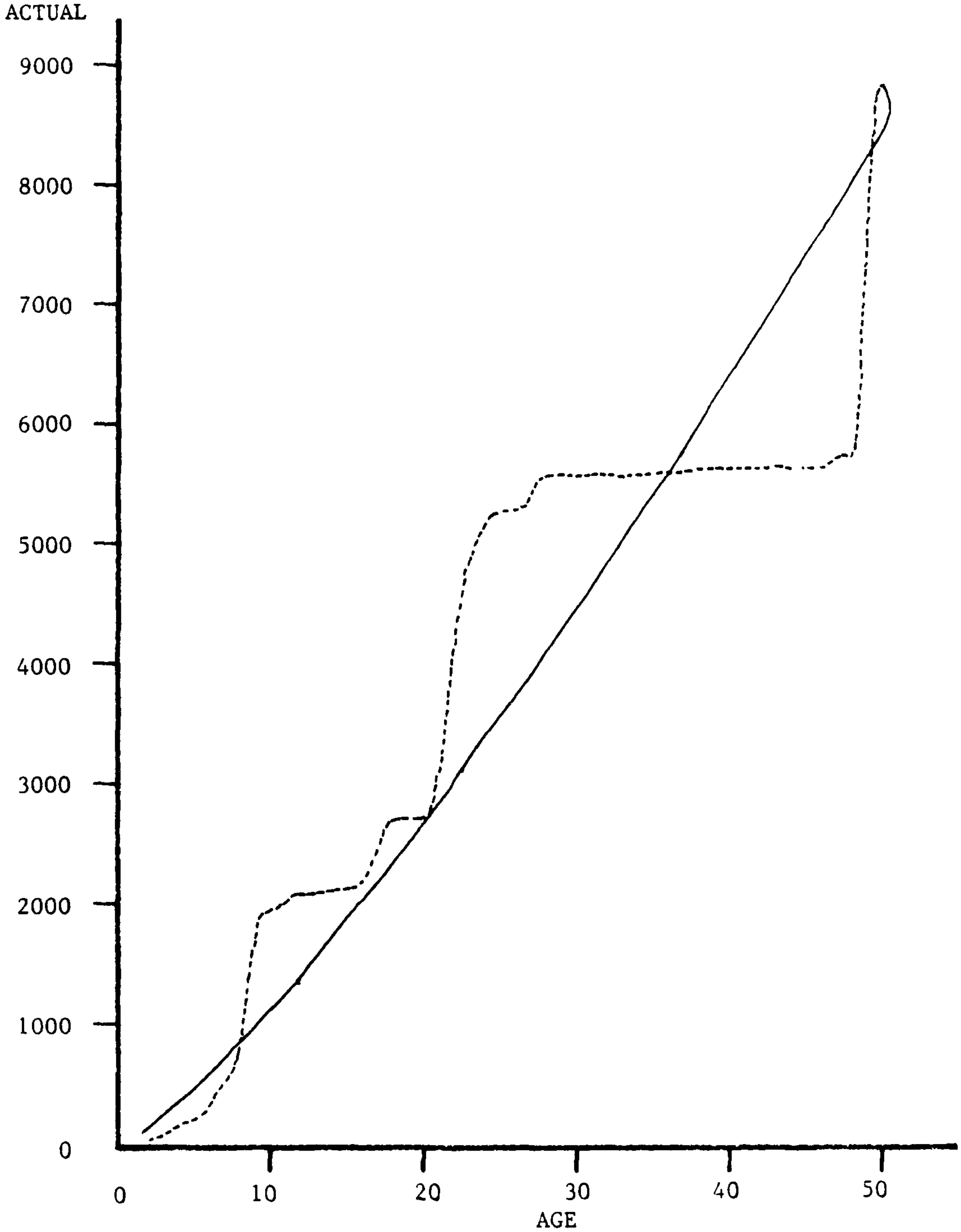

Figure 20 (Con't)

d. 1985 Data

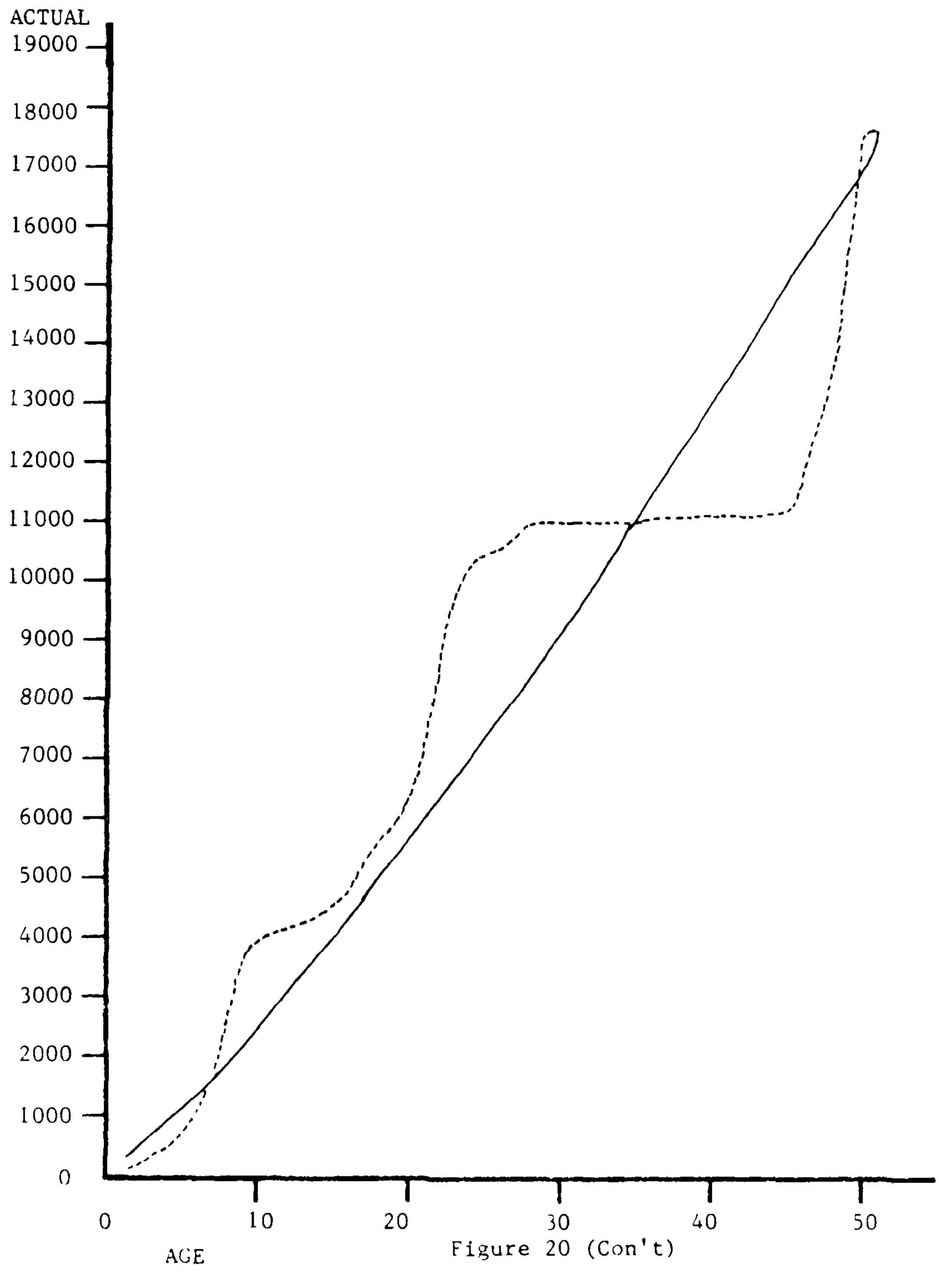

Figure 20 (Con't)

e. All Data Combined

IV. DISCUSSION

A. RELATION OF RESULTS TO HYPOTHESIS

The hypothesis of this study suggested that the maintenance performed on building structures would follow a Weibull Process curve. This was due to the Weibull Process assumption that a system is repairable and that the failures of a system occur along a time line. By examining data on a building or set of buildings, the time to failure from the time these structures were built is noted. These values were the inputs to testing this theory.

However, as was shown in the previous section, the test model and the goodness-of-fit test showed that this set of data did not follow the Weibull Process curve or support the basic hypothesis. Since the major assumptions made in this study were concerned with the data set, the data were examined to find a probable cause for these findings.

B. LIMITATIONS OF STUDY

This study had several major assumptions constraining the data. The first constraint was that the data set combined all the buildings and treated them as identical structures of varying ages. This of course is not the case in reality. These buildings differ in construction, usage, location, and especially, in the manner in which they are maintained. Some buildings might have been unused during periods when the installation was closed. This was seen in the number of buildings that had little to no maintenance done during the course of the study, Figures 10 and 14.

The second assumption made with the data is that it covers the life

of the system, from the time the system was built until present. However, there is only four years worth of data and the system is over 40 years old. This data only gives a window look at the actual maintenance that was done on the system. Thus, an additional assumption is that the amount of maintenance on a building of a certain age during those four years is the amount of maintenance for all buildings when they reach that same age.

Using the data set in the manner described has affected the outcome of the test of the Weibull Process. More careful sorting of the data into different subsets could have an enormous effect on the validity of the Weibull Process to accurately predict future maintenance.

V. CONCLUSION

This study was designed to test the use of the Weibull Process for forecasting building maintenance. Data were provided by the DEH at Fort Leonard Wood on maintenance performed on 2549 structures. These buildings were assumed to be identical in structure for the purpose of this study.

The Weibull Process model used the time interval from time of construction completion until the maintenance was performed to estimate the parameters. The β parameter was found to be approximately 1.2 indicating a deteriorating system. However, when the model was tested with that value in the goodness-of-fit test, the chi-squared value showed that the data did not fit the Weibull Process curve.

As a result of these tests, it was assumed that the constraints on the data forced this conclusion. It is predicted that if the data is separated by individual building or by structure type, the data would follow the Weibull Process curve much more closely. The variance could also be decreased by using data on buildings that are only as old as the number of years of data available. This would mean that this study would have been limited to buildings that were built in 1981 or later. This would give a better picture of the history of maintenance actions.

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VITA

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APPENDIX A

Fort Wood IFS Data Description

This data description is based on the U.S. Army Integrated Facility System Data Dictionary as of June 1986.

COLUMN	FIELD LENGTH	NAME	DESCRIPTION
1	2	FILETYPE	'01' = HISTORICAL RECORDS
3	9	DOC-NO	DOCUMENT NUMBER
12	2	HDR-TRL-CD	HEADER/TRAILER CODE
14	9	FAC-NO	FACILITY NUMBER
23	7	FUNCTL-CRP-CD	FUNCTIONAL GROUP CODE
28	7	F4C	FACILITY CLASS CATEGORY CODE
30	10	OTH-FD-CITA	OTHER FUND CITATION
40	3	PRIOR-IJO	PRIOR IJO
43	1	APVL-DSPVL-ACTN	APPROVAL DISAPPROVAL ACTION
44	1	COMPLD-CD	COMPLETION CODE
45	27	JOB-DESCR	JOB DESCRIPTION
72	15	RMKS	REMARKS
84	7	F4C	FACILITY CLASS CATEGORY CODE
94	8	DSG-COST-EST	DESIGN COST ESTIMATE
102	6	DATE-JOR	DATE JOB ORDER RECEIVED
108	6	DATE-OF-APVL	DATE OF APPROVAL
114	6	DTE-TO-EN-DSG	DATE TO ENGINEER DESIGN
120	6	DATE-DSG-STRT	DATE DESIGN START

126	6	DATE-DSG-CMPL	DATE DESIGN COMPLETE
132	6	DATE-TO-ESTR	DATE TO ESTR
138	6	DATE-TO-PC	DATE TO PC
144	6	DATE-BID-OPEN	DATE BID OPEN
150	6	DTE-EST-JB-ST	DATE ESTIMATED JOB WILL START
156	6	DT-EST-JB-CPL	DATE ESTIMATED JOB COMPLETED
162	6	DATE-JB-CMPLD	DATE JOB COMPLETED
168	6	DATE-SOO-STRT	DATE SERVICE ORDER START
174	6	DATE-SOO-TERM	DATE SERVICE ORDER TERMINATE
180	6	DATE-REC-ESTD	DATE RECORD ESTABLISHED
186	6	DTE-LAST-ACTN	DATE OF LAST ACTION
192	5	RLTN-CD	RELATION CODE
197	1	SPEC-EXTR-IND	SPECIAL EXTRACT INDICATOR
198	5	INSTL-NO	INSTALLATION NUMBER
203	2	REIMB-CD	RE-IMBURSE CODE
205	1	PRIOR-SO	PRIOR SERVICE ORDER
206	6	DT-NOTC-TO-PRCDT	DATE OF NOTICE TO PROCEED
211	30	CONTR-DFCNS-2	CONTRACT DEFICIENCIES - 2
241	30	CONTR-DFCNS-3	CONTRACT DEFICIENCIES - 3
271	30	CONTR-CFCNS-4	CONTRACT DEFICIENCIES - 4
301	8	CONTR-NO	CONTRACT NUMBER
310	15	CONTR-NAME	CONTRACT NAME
325	10	CONTR-AMT	CONTRACT AMOUNT
335	8	CONTR-TYPE	CONTRACT TYPE
343	3	PCT-JOB-COMPL	PERCENT JOB COMPLETE
346	6	DATE-TO-TECH-R1	TECHNICAL REVIEW DATES 1
352	6	DATE-FM-TECH-R1	DATE TO TECHICAL REVIEW

358	6	TO-MATL-COORD-1	DATE TO MATERIAL COORDINATION
364	6	DATE-TO-SCDL-1	DATE TO SCHEDULING 1
370	6	DATE-TO-SHP-1	DATE TO SHOP 1
376	6	DATE-CONT-AWD	DATE CONTRACT AWARDED
382	9	FACILITY-NR-1	FACILITY NUMBER
391	9	FACILITY-NR-2	FACILITY NUMBER
400	9	FACILITY-NR-3	FACILITY NUMBER
409	9	FACILITY-NR-4	FACILITY NUMBER
418	9	FACILITY-NR-5	FACILITY NUMBER
427	9	FACILITY-NR-6	FACILITY NUMBER
436	9	FACILITY-NR-7	FACILITY NUMBER
445	9	FACILITY-NR-8	FACILITY NUMBER
454	30	CNTRACT-DFCNS-1	CONTRACT DEFICIENCY -1
484	8	CONTR-MOD-NR-1	CONTRACT MODIFICATION - 1
492	8	CONTR-MOD-NR-2	CONTRACT MODIFICATION - 2
500	8	CONTR-MOD-NR-3	CONTRACT MODIFICATION - 3
508	8	CONTR-MOD-NR-4	CONTRACT MODIFICATION - 4
516	9	AMT-CONTR-MOD-1	AMOUNT NUMBER - 1
525	9	AMT-CONTR-MOD-2	AMOUNT NUMBER - 2
534	9	AMT-CONTR-MOD-3	AMOUNT NUMBER - 3
543	9	AMT-CONTR-MOD-4	AMOUNT NUMBER - 4
552	6	MOD-ISSUED-DT-1	MODIFICATION ISSUE DATE - 1
558	6	MOD-ISSUED-DT-2	MODIFICATION ISSUE DATE - 2
564	6	MOD-ISSUED-DT-3	MODIFICATION ISSUE DATE - 3
570	6	MOD-ISSUED-DT-4	MODIFICATION ISSUE DATE - 4
576	6	DATE-DEFI-COR-1	DATE DEFICIENCY NR 1 CORRECTED
582	6	DATE-DEFI-COR-2	DATE DEFICIENCY NR 2 CORRECTED

588	6	DATE-DEFI-COR-3	DATE DEFICIENCY NR 3 CORRECTED
594	6	DATE-DEFI-COR-4	DATE DEFICIENCY NR 4 CORRECTED
600	6	DATE-TO-DSGN-2	DATE TO ENGINEER DESIGN 2
606	6	DATE-TO-DSGN-3	DATE TO ENGINEER DESIGN 3
612	6	DATE-TO-DSGN-4	DATE TO ENGINEER DESIGN 4
618	6	DATE-DSGN-STT-2	DATE DESIGN START 2
624	6	DATE-DSGN-STT-3	DATE DESIGN START 3
630	6	DATE-DSGN-STT-4	DATE DESIGN START 4
636	6	DATE-DSGN-CPL-2	DATE DESIGN COMPLETED 2
642	6	DATE-DSGN-CPL-3	DATE DESIGN COMPLETED 3
648	6	DATE-DSGN-CPL-4	DATE DESIGN COMPLETED 4
654	6	DTE-TO-TCH-RV-2	DATE TO TECHNICAL REVIEW 2
660	6	DTE-TO-TCH-RV-3	DATE TO TECHNICAL REVIEW 3
666	6	DTE-TO-TCH-RV-4	DATE TO TECHNICAL REVIEW 4
672	6	DTE-FM-TCH-RV-2	DATE FM TECHNICAL REVIEW 2
678	6	DTE-FM-TCH-RV-3	DATE FM TECHNICAL REVIEW 3
684	6	DTE-FM-TCH-RV-4	DATE FM TECHNICAL REVIEW 4
690	6	DTE-TO-ESTM-2	DATE TO ESTIMATE 2
696	6	DTE-TO-ESTM-3	DATE TO ESTIMATE 3
702	6	DTE-TO-ESTM-4	DATE TO ESTIMATE 4
708	6	DTE-TO-MAT-CD-2	DATE TO MATERIAL COORDIN 2
714	6	DTE-TO-MAT-CD-3	DATE TO MATERIAL COORDIN 3
720	6	DTE-TO-MAT-CD-4	DATE TO MATERIAL COORDIN 4
726	6	DATE-TO-SCDL-2	DATE TO SCHEDULING 2
732	6	DATE-TO-SCDL-3	DATE TO SCHEDULING 3
738	6	DATE-TO-SCDL-4	DATE TO SCHEDULING 4
744	6	DATE-TO-SHOP-2	DATE TO SHOP 2

750	6	DATE-TO-SHOP-3	DATE TO SHOP 3
756	6	DATE-TO-SHOP-4	DATE TO SHOP 4
762	6	DATE-TO-PC-2	DATE TO PC 2
768	6	DATE-TO-PC-3	DATE TO PC 3
774	6	DATE-TO-PC-4	DATE TO PC 4
780	6	DATE-BID-OPEN-2	DATE BID OPEN 2
786	6	DATE-BID-OPEN-3	DATE BID OPEN 3
792	6	DATE-BID-OPEN-4	DATE BID OPEN 4
798	6	DTE-CTRCT-AWD-2	DATE CONTRACT AWARDED 2
804	6	DTE-CTRCT-AWD-3	DATE CONTRACT AWARDED 3
810	6	DTE-CTRCT-AWD-4	DATE CONTRACT AWARDED 4
816	6	DATE-JOB-STRT-2	DATE JOB START 2
822	6	DATE-JOB-STRT-3	DATE JOB START 3
828	6	DATE-JOB-STRT-4	DATE JOB START 4
834	6	DTE-EST-JB-CPL-2	DATE ESTIMATE JOB COMPLETE 2
840	6	DTE-EST-JB-CPL-3	DATE ESTIMATE JOB COMPLETE 3
846	6	DTE-EST-JB-CPL-4	DATE ESTIMATE JOB COMPLETE 4

APPENDIX B

Record and Block Sizes for DEH Data

The records in the data provided by DEH had different lengths and the computer software must be changed for each year input so that it can correctly read the tapes. The following is the logical record length (LRECL) and the block size (BLOCK) for each year of data.

YEAR	LRECL	BLOCK
82	350	3500
83	350	3500
84	350	3500
85	350	18900

APPENDIX C

Program TAPEREAD

This program reads the data tape from Fort Leonard Wood and does the first editting of that data. It first checks for the filetype of '01' which is defined as a maintenance record. Second, it checks for the year that maintenance was done. This is because the records do contain dates that are zero or high values that are used in programs the Army has. We are not interested in those records.

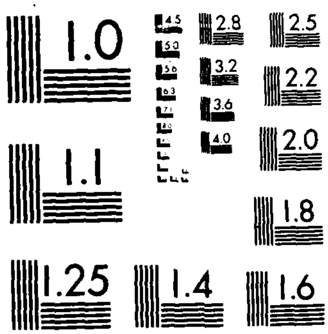
The last statement sorts the records by building number in ascending order and stores them internally in a file designated as save.data*, where the * denotes which year of data was read.

The inputs to this program are the tape volume/serial numbers, the logical record length, and the block size (these are given on the next page). Finally, a distribution name needs to be input for designating the output file.

```
// EXEC TSAS,SOUT=W,OUTLIM=5000
//INDATA1 DD UNIT=(TAPE,,DEFER),LABEL=(2,BLP),
//            VOL=SER=XXXXXX,DISP=OLD,
//            DCB=(LRECL=350,BLKSIZE=3500,RECFM=FB,DEN=3)
//         DD UNIT=AFF=INDATA1,LABEL=(2,BLP),
//            VOL=SER=XXXXXX,DISP=OLD,
//            DCB=(LRECL=XXX,BLKSIZE=XXXX,RECFM=FB,DEN=3)
//SAVE DD DSN=USER.X3388.XXXXXX.SASDATA,DISP=OLD
//SYSIN DD *
DATA TAPEDAT1;
  INFILE INDATA1;
  INPUT FILETYPE $ 1-2
        BLDG $ 14-22
        YRMAINT $ 102-103
        MNMAINT $ 104-105
        DYMAINT $ 106-107;
IF FILETYPE = '01' THEN DO;
  IF YRMAINT > 70 AND YRMAINT < 87 THEN OUTPUT;
 END;
PROC SORT OUT=SAVE.DATA*;  /* INSERT DATA FILE AT *  */
  BY BLDG;
```

AD-A196 312 FORECASTING BUILDING MAINTENANCE USING THE WEIBULL 2/2
PROCESS(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB
OH A K YEOMAN 1988 AFIT/CI/NR-88-108

UNCLASSIFIED F/G 5/3 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX D

Program MERGEFILES

This program merges the maintenance record file with a building file containing the year built for each building. This step is important for determining the age of the building when the building was maintained.

The only inputs to this program are noted by displays. Since there are four years of data, this program should be run four times with each set of data being stored separately. For testing with different building files, only the SAVE.BLDG line needs to be changed. Currently, there are several building files stored under YEOMAN; BLDG (all buildings), BLDGFHM (all buildings except the family housing and the three outliers), TEMPBLDG (temporary buildings), and PERMBLDG (all permanent and semi-permanent buildings).

```
// EXEC TSAS,SOUT=W,OUTLIM=5000
//SAVE DD DSN=USER.X3388.XXXXXX.SASDATA,DISP=OLD
//SYSIN DD *

DATA TEMP;
  SET SAVE.BLDG;           /*  INSERT BUILDING DATA FILE  */
 PROC SORT; BY BLDG;

DATA MERG;
  SET SAVE.DATA2;          /*  INSERT DATA FILE AT *    */
 PROC SORT; BY BLDG;

DATA MERGE;
  MERGE TEMP MERG;
  BY BLDG;
  IF YRBUILT > 40 AND YRBUILT < 85 AND
     YRMAINT > 70 AND YRMAINT < 87 THEN DO;
       TIMEINT = (((YRMAINT - YRBUILT) * 12) + MNMAINT) - 6;
       IF TIMEINT < 0 THEN TIMEINT = TIMEINT + 6;
       OUTPUT MERGE;
  END;

 DATA SAVE.ALL*;           /*  INSERT DATA FILE AT *    */
   SET MERGE;
```

APPENDIX E
Program COUNT

This program counts the number of maintenance actions for each building and determines the age of the building when the maintenance was done. This outputs a file which is used extensively in the Weibull Process and evaluation.

The inputs to this file are the data files for each year and which building file that is being tested. In procedure SIX, the year of data must be entered to aid in determining the age of the building.

```
// EXEC TSAS,SOUT=W,OUTLIM=5000
//SAVE DD DSN=USER.X3388.XXXXXX.SASDATA,DISP=OLD
//SYSIN DD *

DATA ONE;
  SET SAVE.ALL*;            /*  INSERT DATA FILE AT *    */

PROC SORT DATA=ONE;
  BY BLDG;

DATA TWO;
  SET ONE;
  IF _N_ = 1 THEN DO;
    COUNT = 0;
    OLDBLDG = BLDG;
    OLDYR = YRBUILT;
  END;
  IF BLDG = OLDBLDG THEN DO;
    COUNT = COUNT + 1;
  END;
  ELSE DO;
    KEEP OLDBLDG OLDYR COUNT;
    OUTPUT;
    COUNT = 1;
    OLDBLDG = BLDG;
    OLDYR = YRBUILT;
  END;
  RETAIN OLDBLDG COUNT OLDYR;

DATA THREE;
  SET TWO;
  BLDG = OLDBLDG;
  YRBUILT = OLDYR;
  KEEP BLDG YRBUILT COUNT;

DATA FOUR;
  SET THREE;
PROC SORT; BY BLDG;

DATA FIVE;
  SET SAVE.BLDG;            /*  INSERT BUILDING FILE   */
PROC SORT; BY BLDG;
```

```
DATA SIX;
  MERGE FOUR FIVE; BY BLDG;
  IF COUNT = '.' THEN COUNT = 0;
  AGE = 8* - YRBUILT;       /* INSERT YR OF DATA + 1 AT *   */
      /* INSERT YEAR OF DATA + 1 AT *     */
  IF YRBUILT < 8* THEN OUTPUT;

DATA SAVE.COUNT*;     /*  INSERT DATA FILE AT *    */
  SET SIX;
```

APPENDIX F
Program AVERAGE

This program computes the average number of maintenance for all buildings that are the same age. These values are used in computing the Weibull Process para- meters and other tests. The program uses all the data that is currently available on buildings.

Inputs to this program are the year of the data and the year file. Also, the titles for the output must be changed.

```
// EXEC TSAS,SOUT=W,OUTLIM=5000
//SAVE DD DSN=USER.X3388.XXXXXX.SASDATA,DISP=OLD
//SYSIN DD *

DATA ONE;
  SET SAVE.BLDG END=EOF;      /* INSERT BUILDING FILE */
  ARRAY YR(I) YR1-YR50;
  YEARDATA = 8*;              /*  INSERT YEAR OF DATA */
  IF _N_ = 1 THEN DO;
    DO _I_ = 1 TO 50;
      YR = 0;
    END;
  END;
  IF (YRBUILT  > (YEARDATA - 1))
      THEN YRBUILT = YEARDATA - 51;
  DO I = 1 TO 50;
    IF (YEARDATA - YRBUILT) = I
         THEN YR = YR + 1;
  END;
  IF EOF THEN DO;
    KEEP YR1-YR50;
    OUTPUT;
  END;
  RETAIN YR1-YR50;

DATA TWO;
  SET SAVE.ALL* END=EOF;      /* INSERT BUILDING FILE */
  ARRAY CNT(I) CNT1-CNT50;
  YEARDATA = 8*;              /* INSERT YEAR OF DATA */
  IF _N_ = 1 THEN DO;
    DO _I_ = 1 TO 50;
      CNT = 0;
    END;
  END;
  IF (YRBUILT > (YEARDATA - 1))
       THEN YRBUILT = YEARDATA - 51;
  DO I = 1 TO 50;
    IF (YEARDATA - YRBUILT) = I
         THEN CNT = CNT + 1;
  END;
```

```
  IF EOF THEN DO;
     KEEP CNT1-CNT50; OUTPUT;
  END;
  RETAIN CNT1-CNT50;

DATA THREE;
  SET ONE; SET TWO;
  ARRAY YR(I) YR1-YR50;
  ARRAY CNT(I) CNT1-CNT50;
  YEARDATA = 8*;              /* INSERT YEAR OF DATA */
  COUNTEND = YEARDATA - 39;
  DO I = 1 TO 47;
    IF YR = 0 THEN AVERAGE = 0;
             ELSE AVERAGE = CNT / YR;
    AGE = I;
    NUMBBLDG = YR;
    NUMMAINT = CNT;
    KEEP AGE NUMBBLDG NUMMAINT AVERAGE YEARDATA;
    OUTPUT THREE;
  END;

DATA SAVE.AGE*;           /* INSERT DATA FILE  */
  SET THREE;

PROC PRINT DATA=THREE;
  TITLE1 'NUMBER OF MAINTENANCE ACTION AND
         NUMBER OF BUILDINGS BUILT';

PROC PLOT DATA=THREE;
  PLOT AVERAGE*AGE='*';
  TITLE 'AVERAGE NUMBER OF MAINTANENCE ACTIONS
        BASED ON AGE OF BUILDING';
  TITLE2 'FOR YEAR 198*';   /* INSERT YEAR OF DATA  */
```

APPENDIX G
Program WEIBULL, Test Version

This program shows the validity of the Weibull Process software. The data is from a known source and the results can be checked. The only difference between this software and the software used against the building data is that this job is set up to run interactively, and the building data file is run batch because of the volume of data.

There are no special inputs to this program.

```
GOPTIONS DEVICE=CAL1051;
CMS FILEDEF 14 DISK XXXXXX CALCOMP;

DATA ONE;
 INPUT AGE COUNT * *;
  CARDS;
   .2 1    4.2 1    4.5 1    5.0 1    5.4 1    6.1 1    7.9 1
 14.8 1   19.2 1   48.6 1   85.8 1 108.9 1 127.2 1 129.8 1
150.1 1 159.7 1 227.4 1 244.7 1 262.7 1 315.3 1 329.6 1
404.3 1 486.2 1
;

DATA TWO;
  SET ONE END=EOF;
  IF _N_ = 1 THEN DO;
    KOUNT = 0; SUMLX = 0;
  END;
  T = 500;
  KOUNT = KOUNT + COUNT;
  DO I = 1 TO COUNT;
    SUMLX = SUMLX + LOG(T / AGE);
  END;
  IF EOF THEN DO;
    BETAHAT = KOUNT / SUMLX;
    THETAHAT = T / (KOUNT**(1 / BETAHAT));
    LAMBDA = KOUNT / (T**BETAHAT);
    OUTPUT;
  END;
  RETAIN SUMLX KOUNT;

PROC PRINT;
  TITLE1 'WEIBULL PARAMETERS';
  VAR BETAHAT LAMBDA THETAHAT KOUNT SUMLX;

DATA FOUR;
  SET ONE;
  BETAHAT = .413;
  LAMBDA = 1.769;
  CDF = LAMBDA * BETAHAT * (_N_**(BETAHAT-1));
  TIME = _N_;
  OUTPUT;

PROC PLOT;
```

```
  PLOT CDF*TIME='*';
  TITLE1 'CDF PLOT';

GOPTIONS COLORS=(BLACK BLACK BLACK BLACK BLACK);
TITLE1 .H=2 'CDF FOR TEST DATA';
SYMBOL1 V=NONE I=SPLINE L=1;
SYMBOL2 L=2 V=NONE;

PROC GPLOT DATA=FOUR;
  PLOT CDF*TIME;
```

APPENDIX H
Program CHI, Test Version

This program computes the chi-squared statistic for evaluating the goodness of fit to the Weibull Process. The value for betahat is generated in the previous program, WEIBULL. No other inputs are necessary.

```
CMS FILEDEF TEST DISK TESTWP SASDATA;

DATA CHI;
  INFILE TEST;
  COUNT = 23;
  BETAHAT = .412738;
  T = 500;
  K = INT(COUNT / 5) + 1;
  DF = K - 2;                      /* DEGREES OF FREEDOM */
  ARRAY PROB(5) PROB1-PROB5;       /* PROBABILITY ARRAY  */
   ARRAY OCCUR(5) OCCUR1-OCCUR5;       /* OCCURRENCE ARRAY
*/
  DO I = 1 TO 5;
    PROB(I) = 0;                   /* INITIALIZE ARRAYS  */
    OCCUR(I) = 0;
  END;
  DO I = 1 TO (K-1);
    PROB(I) = T * ((I / K)**(1 / BETAHAT));
  END;
  PROB(K) = 999999;        /* PROBABILITY OF LAST CELL */
  EXPNUMB = COUNT / K;    /* EXPECTED NUMBER IN EACH CELL */
  DO I = 1 TO COUNT;
    INPUT TIMEINT;
    J = 1;
    DO WHILE (J < (K+1));
      IF TIMEINT < PROB(J) THEN DO;
        OCCUR(J) = OCCUR(J) + 1;
        J = K+1;
      END;
      J = J + 1;
    END;  /*  DO WHILE  */
  END;
  CHI = 0;
  ZEROS = 0;
  DO I = 1 TO K;
    TIMES = OCCUR(I);
    IF OCCUR(I) = 0
      THEN ZEROS = ZEROS + 1;
      ELSE CHI = CHI + (((OCCUR(I) - EXPNUMB)**2) / EXPNUMB);
  END;
  RETAIN OCCUR1-OCCUR4 PROB1-PROB4;

 PROC PRINT;
  VAR T COUNT BETAHAT EXPNUMB CHI DF;
  TITLE1 'CHI SQUARED GOODNESS OF FIT TEST';
```

APPENDIX I
Program REGRESSION

This program plots the maintenance versus age graph, does a regression analysis, and then uses the data for a simple mean package that is standard in SAS. It also breaks the data into four categories based on age and plots the graphs and runs the regression analysis again. All the data is used in these procedures, not the averages from the proceding program.

Input to this program is the count data files for each year.

```
// EXEC TSAS,SOUT=W,OUTLIM=5000
//SAVE DD DSN=USER.X3388.XXXXXX.SASDATA,DISP=OLD
//SYSIN DD *

DATA ONE TWO THREE EIGHT FOUR;
  SET SAVE.COUNT*;
  OUTPUT ONE;
  IF AGE < 9  THEN OUTPUT EIGHT;
    ELSE IF AGE < 26 THEN OUTPUT TWO;
      ELSE IF AGE < 41 THEN OUTPUT THREE;
        ELSE OUTPUT FOUR;

PROC PLOT DATA=ONE;
  PLOT COUNT*AGE='*';
  TITLE1 'PLOT OF MAINTENANCE VS AGE FOR 198* DATA';

PROC REG DATA=ONE;
  MODEL COUNT = AGE / DW;
  TITLE1 'REGRESSION ANALYSIS FOR 198* DATA';

PROC PLOT DATA=EIGHT;
  PLOT COUNT*AGE='*';
  TITLE1 'PLOT OF MAINTENANCE VS AGE FOR 198* DATA';
  TITLE2 'BUILDING AGE 1 TO 8';

PROC REG DATA=EIGHT;
  MODEL COUNT = AGE / DW;
  TITLE1 'REGRESSION ANALYSIS FOR 198* DATA';
  TITLE3 'BUILDING AGE 1 TO 8';

PROC PLOT DATA=TWO;
  PLOT COUNT*AGE='*';
  TITLE1 'PLOT OF MAINTENANCE VS AGE FOR 198* DATA AGE 9 TO
25';

PROC REG DATA=TWO;
  MODEL COUNT = AGE / DW;
  TITLE1 'REGRESSION ANALYSIS FOR 198* DATA';
  TITLE3 'BUILDING AGE 9 TO 25';
```

```
PROC PLOT DATA=THREE;
  PLOT COUNT*AGE='*';
  TITLE1 'PLOT OF MAINTENANCE VS AGE FOR 198* DATA AGE 26 TO
40';

PROC REG DATA=THREE;
  MODEL COUNT = AGE / DW;
  TITLE1 'REGRESSION ANALYSIS FOR 198* DATA';
  TITLE3 'BUILDING AGE 26 TO 40';

PROC PLOT DATA=FOUR;
  PLOT COUNT*AGE='*';
  TITLE1 'PLOT OF MAINTENANCE VS AGE FOR 198* DATA AGE 41 TO
45';

PROC REG DATA=FOUR;
  MODEL COUNT = AGE / DW;
  TITLE1 'REGRESSION ANALYSIS FOR 198* DATA';
  TITLE3 'BUILDING AGE 41 TO 45';

PROC SORT DATA=SAVE.COUNT*;      /* INSERT YEAR OF DATA FILE
*/
  BY YRBUILT;

PROC MEANS DATA=SAVE.COUNT*;    /* INSERT YEAR OF DATA FILE
*/
  VAR COUNT;
  TITLE1 'FT LEONARD WOOD BUILDING 198* DATA';
  TITLE4 'SIMPLE MEAN OF DATA';

PROC MEANS DATA=SAVE.COUNT2 MAXDEC=35 NMISS RANGE USS CSS
SKEWNESS
  KURTOSIS T PRT;
  VAR COUNT;
  TITLE '    ';
  TITLE1 'FT LEONARD WOOD BUILDING 198* DATA';
  TITLE4 'REQUESTED STATISTICS';
  OUTPUT OUT=FIVE MEAN=AMEAN STDERR=AERR;
```

APPENDIX J
Program WEIBULL

This program computes the parameter estimates of the Weibull Process using all the data from the maintenance records. It uses the age of the building to determine these values. This program is similar to the test version. Input to this program is the year of the data and the data file for that year.

```
// EXEC TSAS,SOUT=W,OUTLIM=5000
//SAVE DD DSN=USER.X3388.XXXXXX.SASDATA,DISP=OLD
//SYSIN DD *
PROC SORT DATA=SAVE.COUNT*; BY AGE; /* INSERT DATA FILE
*/
DATA TWO;
  SET SAVE.COUNT* END=EOF;          /* INSERT DATA FILE    */
  YEAR = 8*;                        /* INSERT YEAR OF DATA */
  OLDEST = (YEAR + 1) - 40;
  IF _N_ = 1 THEN DO;
    KOUNT = 0; SUMLX = 0;
  END;
  KOUNT = KOUNT + COUNT;
  DO I = 1 TO COUNT;
    SUMLX = SUMLX + LOG(OLDEST / AGE);
  END;
  IF EOF THEN DO;
    BETAHAT = KOUNT / SUMLX;
    THETAHAT = OLDEST / (KOUNT**(1 / BETAHAT));
    OUTPUT;
  END;
  RETAIN KOUNT SUMLX;

PROC PRINT;
  TITLE1 'WEIBULL PARAMETERS';
  VAR YEAR KOUNT BETAHAT THETAHAT;
```

APPENDIX K
Program CHI

This program computes the chi-squared statistic for the actual data. The inputs to this program are the year of data and the betahat value that was computed in the WEIBULL program. The number of records must also be input.

```
// EXEC TSAS,SOUT=W,OUTLIM=5000
//SAVE DD DSN=USER.X3388.XXXXXX.SASDATA,DISP=OLD
//SYSIN DD *

DATA CHI AA;
  SET SAVE.COUNT* END=EOF;
  ARRAY PROB(I) PROB1-PROB46;
  ARRAY OCCUR(I) OCCUR1-OCCUR46;
  ARRAY EXPNUM(I) EXPNUM1-EXPNUM46;
  YEAR = 8*;
  OLDEST = (YEAR + 1) - 40;
  KOUNT = ****;
  BETAHAT = ********;
  IF _N_ = 1 THEN DO;
    BIN = 46;
    DF = BIN - 2;
    DO I = 1 TO BIN;
      PROB = 0;
      OCCUR = 0;
    END;
    DO I = 1 TO BIN;
      IF I < BIN THEN PROB = ((I / OLDEST)**BETAHAT);
        ELSE PROB = 1;
      EXPNUM = KOUNT * PROB;
    END;
  END;
    I = AGE;
    DO J = 1 TO COUNT;
      OCCUR = OCCUR + 1;
  END;
  IF EOF THEN DO;
    CHI = 0; OCCURED = 0;
    DO I = 1 TO BIN;
      OCCURED = OCCURED + OCCUR;
      CHI = CHI + (((OCCURED - EXPNUM)**2) / EXPNUM);
      EXPECTED = EXPNUM;
      AGE = I;
      OUTPUT AA;
    END;
    OUTPUT CHI;
  END;
  RETAIN PROB1-PROB46 OCCUR1-OCCUR46 DF BIN;
  RETAIN EXPNUM1-EXPNUM46 OLDEST BETAHAT;
```

```
PROC PRINT DATA=CHI;
  VAR YEAR BETAHAT CHI DF;
  TITLE1 'CHI SQUARED GOODNESS OF FIT TEST';
  TITLE2 'PER BUILDING';

PROC PLOT DATA=AA;
  PLOT EXPECTED*AGE='E' OCCURED*AGE='A' / OVERLAY;
  TITLE1 'EXPECTED VALUES USING ESTIMATED PARAMETERS';
  TITLE2 'ACTUAL VALUES USING ESTIMATED PARAMETERS';
```